THE UNIVERSITY OF ALBERTA

LAND USE - SNOWMELT RUNOFF RELATIONSHIPS IN THE WHITEMUD CREEK BASIN

by

© JURGEN PETER ERXLEBEN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled LAND USE - SNOWMELT RUNOFF RELATIONSHIPS IN THE WHITEMUD CREEK BASIN submitted by JURGEN PETER ERXLEBEN in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

The purpose of this study is to determine the effects of different land use patterns upon snowmelt runoff in the Whitemud Creek Basin near Edmonton. It is a preliminary study to measure the runoff from different surfaces such as natural woodplots, agricultural lands and paved surfaces. This is in part a bench mark study for additional studies of land use change, as changes to more intensive agricultural and urban use take place. Developments such as the improvement of agricultural practices, expansion of suburban areas, extension of paved roads and construction of an airport in this watershed have altered and are altering surface runoff patterns. It is thus necessary and important to assess and analyze the character and the extent of changes and how they may affect plans for development.

The present land use patterns are closely related to the runoff patterns in the basin. Fourteen different plots were selected for studies of land use - snowmelt runoff relationships. Ninety degree V-notch weirs were installed in three sites and culverts were used in ten sites for runoff measurement. The patterns of runoff that were observed, were analyzed for land use relationships. Factors such as vegetation, aspect, soil and land use were considered.

Observations from the following meteorological stations were used in analyses of the climate of the study area: Edmonton Industrial and International Airports, Calmar and the Ellerslie Farm of the University

of Alberta. Stream discharge records for Whitemud Creek were obtained from the Water Survey of Canada and also from the Alberta Water Resources Division. The Thornthwaite water balance procedure was employed and it was found to be reasonably suitable for water balance caculations for the Edmonton region.

It was found that surpluses for surface runoff occurred in all sub-basins, but not in all parts of all of the sub-basins. Some woodplot depressions apparently subtracted from the surpluses of the adjoining open areas within their sub-basins.

Some preliminary results are that the airport area, including a certain percentage of pavement, had the highest yield and also the flashiest flow. An area devoted to improved pastures and forage crops had the next highest yield. Summerfallow fields were next in yield but the flow from these areas was relatively flashy. Sites which were partly forested had the lowest yields.

The understanding of these snowmelt runoff patterns may lead to better mangement decisions for cultivation practices, control of water erosion, and culvert design in other hydrologically similar areas.

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CHAPTER I

INTRODUCTION AND APPROACH

GENERAL CONSIDERATIONS

Water, whether beneath the ground surface or above the surface, is of tremendous importance to man. It constitutes a valuable source of supply for individuals, communities, industries, agriculture and transportation, and is used extensively for a wide variety of purposes which include domestic cooking and washing, waste disposal and dilution, industrial manufacturing and cooling, farm irrigation, recreation activities and many other uses. It comprises one of the more important natural resources because of its vital necessity not only to man but to all living organisms.

Population has increased steadily and it is constantly increasing in number. At the same time man's technological sophistication is becoming much more precise and refined. Man is very much concerned about water resources and his environment as a whole. Many plans for water resource development have been and are being made at various scales of operation. It is thus also important that man assess the current state of knowledge about watershed behaviour because of his growing impact on the natural environment. Sharp, Gibbs, and Owen (1966) conducted a study for the United States Department of Agriculture, and they stated that much information is available on the effects of

land and watershed treatment on runoff and yield of streamflow. There were though, no proposals or descriptions of comprehensive solutions to the problems.

At a Water Resources Symposium held at the University of Texas, (Moore and Morgan, 1969), three basic methods of approach were noted to be necessary in planning for water resources development. The methods deal with estimating the needs in space and time, evaluating potential sources in space and time, and developing control systems against damaging floods. All the approaches require a thorough understanding of many hydrologic factors affecting supply. In this regard, there are a number of ways in which man, either consciously or unconsciously modifies or alters some phase of the hydrologic cycle. Moore and Morgan (1969) made reference to two areas in which man's activities are altering the hydrologic characteristics of watersheds to an increasing degree. These areas are within the rural and urban environments. Man's impact as a hydrologic modifier is not only being recognized to a greater degree in these areas, but is also very well documented in the literature on forest hydrology. Some developments undertaken in a watershed such as agricultural practices, urbanization, the extension of paved roads and airports and others may tend to alter surface runoff patterns. It is thus important to assess and to analyze the character and the extent of changes and how they may affect plans for development. Alterations within a basin from forest to agriculture, from grassland areas to more intensively cultivated fields, from a rural landscape to an urban environment, and other changes, all affect the runoff patterns. In addition to these changes, areas which may revert back to previous

conditions, all tend to produce effects on the quantity and quality of runoff, as well as on the timing of runoff, and the resultant streamflow.

Results from a study conducted by Hibbert (1969) in the southern Appalachians, show a greater water yield from a catchment which had been converted from forest to grass. In an earlier paper (Hibbert, 1967), it was indicated that in well-watered regions, such as along the Appalachian Mountains, streamflow response is proportional to the reduction in forest cover. That is, as the forest cover is reduced more runoff occurs. Hornbeck, Pierce, and Federer (1970) also showed that sizable streamflow increases, an average of 12.2 area inches for the first two water years, can result from forest clearing in the uplands of the eastern United States.

In the field of urban hydrology, Horner and Flynt (1936) indicated that higher surface runoff results from urban areas due to their impermeable nature. An additional factor is lesser storage by these areas for use in dry periods. Brater (1968) analyzed rainfall and runoff from urban drainage basins in the Detroit area in various stages of urbanization. The study was conducted to determine the initial retention, the hydrologically significant impermeable area, and the infiltration capacities of the permeable portions of the basins. He indicated that a high runoff results from urban areas. Waananen (1961) presented findings that urban growth areas affect runoff to a great degree. He stated that peak snowmelt and rainfall runoff from developed areas in the eastern United States is on the average three to four times greater than that resulting from the same channel further upstream or from adjacent natural areas. The condition will vary from place to place with climatic and other variables. Anderson (1970) again

supported the view that urban developments have a significant impact on hydrologic relations. Meyer, Wischmeier, and Daniel (1971) reported how serious the erosion and runoff process can be due to man's neglect during all types of construction, ranging from surface mining to urban housing. They stated that the hazards of runoff and erosion rates associated with such land modifications are often ignored, even though practical methods for reducing them exist. The authors referred to above are some of the authorities in this field and their conclusions are representative. The end result is that a stream's regime, yield, quality, erosion, sedimentation and other categories are altered greatly with urbanization.

Bruce and Clark (1966) stated that in many parts of the world, cities and towns are growing rapidly and expanding into valuable agricultural lands. They added that forested lands, farms and fields are being replaced by pavements and roofs, and smoke and heat are being generated by the furnaces, vehicles and industries of man. They believed that these processes of expansion and pollution influence all phases of the hydrologic cycle, from precipitation and evaporation to infiltration rates and the hydraulics of overland flow. Since 1966 much has been written on the hydrology of urban watersheds. In 1969, for example, a summary of 70 papers and 17 projects concerned with urban hydrology appeared in the Journal of Hydraulics Division of the American Society of Civil Engineers, but many other sources also exist, for example, AWRA New York Conference 1968 Proceedings.

The unprecedented growth of urban areas has continually created many complex and critical social,political and physical problems. The effects of watershed changes on streamflow tend to result in higher flood

peaks during the spring runoff period, often in critical low flow conditions during the summer months, and in other flow regime characteristics. Within any watershed, spillway structures of all kinds, from culverts to bridges, must be designed for the safe passage of all but the most extremely high discharges. The need for studies in assessing the effects of various types of land use upon the water balance, and of changes in local hydrologic conditions brought about by man's activities is a major reason why this study is directed towards such developments within the Whitemud Creek Basin. The study has a focus upon land use in the basin such as natural bush, agricultural and paved surfaces, and is an assessment of the effects of changes of their relative areas upon the local runoff patterns.

Specifically, the study is an attempt to determine the distributional availability and quantity of runoff waters in the basin, as well as the factors influencing these patterns and water quality. The writer believes that the data that have been assembled for the watershed will be of some assistance, not only to those who may utilize or have a better understanding of the local runoff pattern, but also to those wishing to pursue further research with respect to either a geographical, geological or hydrological perspective. The writer further hopes that the information assembled here may be of some practical value, with reference to better resource conservation and water management practices in this basin and for wider areas.

The explanation of the variations and the interrelationships of changes, and their resulting effects within a physically delimited region is a research technique. The distinct geographical approach to such an interdisciplinary problem is through the explanation of the

spatial distributions of certain factors. In this respect, this study is an examination of the effects of environmental changes upon streamflow characteristics to explain its character at a particular place, time and situation. This study has a focus upon land use changes in the basin and how these affect local runoff, that is, what influences different environmental factors have upon the variations in runoff. The resulting work can be considered geographical research because it involves the investigation of the spatially variable factor (water) in an area, thus our understanding of the distribution of related geographic patterns may be improved. In addition to the foregoing reason, the examination of the spatial character of water and the interpretation of the interrelationships of the environmental factors within the water balance involve the use of geographical research techniques.

REASONS FOR SELECTING AREA AND TOPIC

The reasons for a work choice are sometimes difficult to specify. A prime reason is that the problem which is selected should strongly interest the investigator in order that an original and interesting piece of work may be produced.

In addition to the writer's "interest", there are other reasons that have contributed to the choice of the present research regarding the area and topic involved.

The Whitemud Creek Basin was selected by Dr. A. H. Laycock in 1965 for water balance studies in the International Hydrological Decade programme. It is believed to be representative of Parkland patterns in the Prairie Provinces. The catchment provides a typical physical setting of Central Alberta. Rains (1969) found that the watershed

is "typical" of the local area insofar as the morphological development of the basin was similar to others in the region.

The area has a good long climatic record available from a number of observation stations,(Edmonton Industrial Airport, Thorsby, Calmar, Ministik Sanctuary and others). These climatological data are necessary for the calculation of water balance parameters and the synthesizing of a runoff record.

Four years of streamflow records are available from an automatic gauging station operated by the Water Survey of Canada. Some of the discharge trends from 1969 to 1972 inclusive are discussed in chapter two.

The terrain and vegetation patterns are fairly uniform but local variations are evident. These patterns will also be discussed in greater detail in chapter two.

Within the study area, the University of Alberta owns a large tract of land west of Ellerslie. Two representative runoff plots are located on and near this property.

The equipment and material used in this study were procured with a grant from the federal government department, Environment Canada which was obtained by Dr. A. H. Laycock and administered by him.

The basin area is readily accessible by a number of all-weather and gravel-surfaced roads. On this network it can be reached within a very short time from Edmonton.

The area also has good air photography and map coverage, which are of considerable value in any study. The Department of Geography of the University of Alberta has in its map library aerial photographs at scales of 1:400, 1:1,000 and 1:2,640, and also topographical maps at

different scales from 1:100 to 1:50,000. The 1:400 and 1:1,000 photographs and detailed topographical mapping (2 foot and 10 foot contour intervals) were procured with N.R.C. support to assist in basin studies.

In the study area, relatively recent changes in land use have taken place and these have probably altered the local hydrological characteristics and still others are in prospect as Edmonton's growth southward continues. The changes which have occurred will be discussed in greater detail in chapter three.

Possibly one final reason for choosing this area is its nearness to the city of Edmonton, thus enabling the writer to be constantly aware of changing runoff patterns in the basin. The complete site and situation of the study area will be examined more closely in chapter two.

SCOPE AND PURPOSE OF THE STUDY

The Whitemud Creek Basin is located in an area which receives relatively low precipitation, on the average 17.67 inches annually (89 year mean), yet the annual surpluses and corresponding runoff range from well under 1 inch to over 6 inches, (see Appendix A), or less than 1 per cent to greater than 25 per cent of the precipitation. Most of the runoff takes place in spring and is flashy in nature.

The study focus is upon snowmelt runoff as it is influenced by different land use. Fourteen different sites were selected in the watershed and their specific characteristics are examined in chapter three. Once the runoff data were collected from these drainage areas, the results were analyzed. In chapter four the results of runoff data analyses are presented. The factors that tend to influence the runoff patterns in this area are discussed in chapter five. The study in essence involves

the application of water balance techniques. Surplus water values derived from climatic data through the use of these techniques are compared with streamflow data of the study area so that their usefulness may be assessed.

The objectives of the study can be summarized as follows:

1) The examination of land use changes within the Whitemud Creek Basin as a means for establishing relationships between the effects of these upon their local runoff characteristics.

2) The observation of the effects of some existing land use in the basin on runoff patterns, in order to provide a comparative reference point for future measurements following further alterations in use.

3) The collection of water samples for chemical analysis from representative sites so that qualities of surface runoff waters may be assessed and related to various environmental conditions.

4) Testing the use of existing cúlverts and temporary 90 degree sharp-crested V-notch weirs for the purpose of measuring surface snowmelt runoff from fourteen sites. This is done to assess the accuracy of the measuring techniques.

5) A final objective is the testing of methods and techniques for observation. Even though a longer period of observation is desirable, and only preliminary conclusions are derived, the study provides a basis for future observations.

The primary purpose of the study is to provide a preliminary interpretation and evaluation of the effects of land use changes on runoff. It is realized that a longer term is needed for more than preliminary conclusions.

WATER BALANCE ESTIMATION FROM CLIMATIC DATA

The water balance concept as presented by C. W. Thornthwaite in the 1940's (1945, 1948) is an approach to the study of the quantities of water moving through the hydrologic cycle. Thornthwaite's technique is merely one of the more convenient expressions of the water balance. Several other authors including Penman (1948); Blaney and Criddle (1962); Baier (1963), and others also employ a similar concept regarding potential evapotranspiration or consumptive use but the approach varies. In employing Thornthwaite's empirical technique, a relationship is established between incoming precipitation and outflow of surplus water or runoff for a place through time. In addition to this relationship, changes in stored water within a region or smaller areal unit, must also be considered. This relationship of climatic factors can be expressed by means of a formula as follows:

$$\text{Ppt} = (\text{PE} - \text{D}) + \text{Sur} \pm \text{SC}$$

where: Ppt = precipitation,
PE = potential evapotranspiration,
D = deficit,
Sur = surplus,
SC = storage change.

Brief definitions of each term follow:

Precipitation: rain, snow, and moisture that has condensed directly upon the earth's surface from the atmosphere;
Potential evapotranspiration: the moisture lost by evaporation and transpiration under optimum moisture conditions, (i.e., soil constantly at field capacity);
Deficit: the difference between optimum moisture demands (i.e., PE) and the amount of moisture that is actually available for evapotranspiration, (or that part of demand that cannot be supplied by precipitation and soil moisture storage);
Surplus: the amount of incoming moisture (i.e., Ppt) that exceeds the demand (i.e., PE) when soil moisture retention is at field capacity to the root depth. This includes both surface and groundwater flow;
Storage change: the increase or decrease of moisture stored at a specific site in the form of soil moisture and surface detention

for the period under consideration.

The result of subtracting the deficit from the potential evapotranspiration (that is., PE-D) equals the amount of moisture that is actually consumed through evaporation and transpiration, or the actual evapotranspiration (AE).

The water balance approach can be employed to derive useful information for certain types of land use areas. The approach provides a point evaluation of water surplus or runoff for any station where data of temperature and precipitation are available. The empirical formula can be used in calculating monthly values for unknown variables from known variables of precipitation, available soil moisture storage and temperature. It might also be used, if surpluses are known, in working out, for example, probable precipitation in higher parts of a basin. The formula can be utilized to direct attention towards water deficiency, water surplus, or changes in moisture storage, for whichever variable data are deficient.

Thornthwaite (1948) pointed out in the article "An approach toward a rational classification of climate" that the water balance technique can be used for: 1) estimating historical data that were not originally collected (for example, runoff or evapotranspiration), provided the necessary meteorological variables are available, 2) expanding present limited networks of observation, and 3) adapting to any vegetation or soil condition by adjusting the value for available soil moisture storage or retention.

Since Thornthwaite introduced a more convenient expression of the water balance concept, it has been widely used as an analytical tool. A number of researchers have constructed maps portraying spatial patterns

of components derived from water balance calculations, for example, Thornthwaite and Mather (1955); Thornthwaite, Mather, and Carter (1958); Laycock (1967); Sanderson and Phillips (1967).

Thornthwaite and Mather (1955) indicated locations which illustrate the accuracy with which calculated water balance surplus estimates approximately equalled discharge. In an article, Thornthwaite, Mather and Carter (1958) wrote that the calculated water surplus is equal to (measured) streamflow in its yearly total. When local conditions are considered, within limits, the seasonal pattern of runoff from computed surplus values will approximately equal the measured values. One of the aims of this study is to apply the water balance approach to various representative areas within the Whitemud Creek Basin. This is done in order to arrive at more precise estimates of runoff, or to provide a better local basis for improving the estimates with actual field measurements.

Several researchers, who used the Thornthwaite water balance method, report relatively good correlations between the measured discharge and computed surplus values. Thornthwaite and Mather (1955) referred to several reports which considered watersheds of various sizes, and in each case there was a close agreement between computed runoff and measured runoff. Sanderson and Phillips (1967) verified the fact that good agreement exists between calculated and measured values of runoff. Laycock (1967) also used the water balance method to obtain a series of maps indicating water deficiency and surplus patterns in the Prairie Provinces. Kakela (1969) examined the importance of snow in a subarctic region, and its relationship to the Thornthwaite Water Balance. He computed values of runoff and measured the actual runoff and found good

agreement between them. He does mention that more refinements have to be made before Thornthwaite's method can be fully applied to a subarctic environment. There also appears to be a reasonably close correlation between surplus patterns based upon this type of calculation and regional lake levels (for example, Cooking Lake brief by A.H. Laycock,August,1971). From the evidence presented by the foregoing authors and from preliminary calculations for this area, the writer believes that the water balance method can also be applied in this study, with considerable assurance of obtaining results which have a reasonable degree of accuracy.

DELIMITING THE BASIN

Stichling and Blackwell (1967) discussed a basic problem in the delimitation of basin area of prairie watersheds: that of depressional storage.

Gray (1964) noted that depressional storage in large watersheds may affect the annual peak discharges. The total area contributing surface runoff to the main channel may vary with differing storm conditions, snow accumulation, soil moisture characteristics and other factors. Depending on these foregoing circumstances small slough catchments may contribute runoff to the main channel and at other times may not.

The method of delimiting a basin is purely subjective and besides other factors depends on the experience of the interpreter and the objectives of the study. Rains (1969) had already delimited the basin area for this study. Further field checking in uncertain areas of the drainage basin divide for the main basin was carried out during the spring snowmelt periods of 1971 and 1972. The divides of the smaller sub-basins or representative sites were also noted at these times.

Additional information was obtained by stereoscopic scanning of aerial photographs. The areas of the fourteen sub-drainage basins were calculated with the use of a dot planimeter.

The whole basin area was traversed several times during the course of the study, but especially during the spring runoff of 1971 and 1972. At these times the snowmelt period was well in progress and the direction of flow in channels could be noted. In this manner a relatively accurate estimate, of the locations of the smaller sub-drainage basins' divides was obtained. It is believed that a sufficient degree of accuracy for comparative purposes of surface runoff results has been attained.

Once a drainage basin has been delimited as a natural unit it can be examined much more closely. The basin reflects interactions of soil, geology, water and vegetation by providing a common product- runoff or streamflow- whereby the net effects of these interactions and others on that product can be measured and appraised (Lassen, et. al., 1952).

THE MEASUREMENT OF RUNOFF

Use of V-notch Weirs

Weirs are the simplest and most reliable structures that can be used for measuring the flow of water. A weir is defined as a small dam, either natural or artificial construction, built in a river or stream. To facilitate measurement of spring runoff, 90 degree V-notch weirs were installed at three representative locations within the basin. The weir sites were selected in April and May 1971, during which time maximum snowmelt and runoff took place. The location of suitable sites

under variable land use for the measurement of runoff was achieved with some difficulty. Many excursions into the study area were taken to decide upon the selected sites.

Certain criteria were used in the final selection of the sites. Considerations were given to the ease with which a plot's boundaries could be defined and clearly delimited, the plot having a simple outlet which facilitated the construction of a dam so that the weir intercepted all the runoff, the gradient was sufficient for the free flow of water, accessibility to the sites, finally, the sites for runoff measurements were representative of different surficial material, vegetation, aspect and land use patterns. Each of the 14 sites was different from the others, and each was representative of a part in the basin, that is, pertaining to the above criteria. Once the sites had been selected on the above criteria, the weirs were installed during the summer of 1971.

Installation Procedures for Weirs

The following procedures were used to install the V-notch weirs to minimize or prevent seepage, and to obtain a relatively high level of accuracy in flow measurements.

A dam was constructed at the outlet of each sub-basin selected. The main part of each dam consisted of a sheet of three-quarter inch plywood. A small trench between eight and twelve inches deep and the width of a shovel was dug across the outlet. The plywood sheet was then placed into the trench and positioned so that it was vertical. The dam was then sealed by first lining the trench on both sides of the dam with bentonite and then backfilling with a mixture of bentonite and soil. Bentonite is used in well drilling operations for sealing voids and pores. It is a colloidal clay which swells to a much larger volume

when wetted. This characteristic of bentonite makes it a satisfactory sealant and creates an impervious barrier. The dams were further reinforced with rocks and debris on both up- and downstream sides. The drainage channels below the weir notches were lined with rocks to reduce erosion around the gauge.

The plywood was then fitted with a 90 degree V-notch weir plate and a gauging stake. This stake, calibrated in hundredths of a foot, was attached to the upstream side of the plywood dam to facilitate reading of the flow-head through the weir crest.

There are certain specifications set out by the Canada Water Survey for this type of weir and these should be followed in order that reasonable measurements of runoff may be obtained. The specifications were adhered to in this study as closely as possible. The standard 90 degree V-notch weirs used in this study were constructed from three-sixteenth inch sheet metal with a six-inch 90 degree V-notch cut in the centre of the plate. The downstream side of the V is bevelled at an angle of forty-five degrees. These weir plates were fastened with stove bolts to the downstream sides of the plywood dams across the outlets of the runoff plots. Plate 1 shows one of the nonrecording 90 degree V-notch weirs used in the collection of snowmelt runoff data. Before the plates were fastened, roofing tar was applied onto the plates to prevent seepage of water between them and the plywood dam. Landals (1970), in his study of surface runoff from snowmelt in the Yellowknife area in the Northwest Territories, employed the same type of weir construction, and obtained relatively good results.

In order that accurate flow measurements may be made, weirs must be installed so that a stilling pond is provided upstream, which

PLATE 1

One of the six inch sharp-crested 90 degree V-notch weirs used for measuring runoff in this study. This particular one was located at the outlet of site 13 in the headwaters of Whitemud Creek. The photo was snapped on April 20, 1972, before the April 21 snowstorm. On that day the staff gauge read 0.08 feet and discharge was calculated at 0.01 cubic feet per second.

The dam across the outlet, the V-notch steel plate, the staff gauge on the left side of the notch, the debris below the notch and the ditch for drainage below the weir are all evident on the plate.

effectively reduces the velocity of the approaching water. In addition to correct installation of weirs, they must be constructed in such a way as to afford free flow of water and that the nappe breaks completely free on the downstream side of the weir plate. The Water Measurement Manual published by the U. S. Department of the Interior, Bureau of Reclamation (1971), recommended ten conditions to be followed for setting up and operating in order to ensure reliable results from standard 90 degree V-notch weirs.[1] These provisions are designed for measurement of flow in irrigation channels and are impossible to be met in every case under the much different conditions prevailing in the basin. These provisions were adhered to as closely as possible in this study. Thus the author believes that a reasonable degree of accuracy was maintained during the flow measurements.

Use of Culverts

In addition to using weirs, existing culverts within the drainage basin were also employed for measuring runoff in ten other plots. The discharge characteristics of culverts have been studied in laboratory investigations by the U. S. Geological Survey, the Bureau of Public Roads, and many universities. Neill (1962) conducted experiments on large sixty-inch corrugated culverts to establish hydraulic capacities and roughnesses for these. Knapp, Schaake and Viessman (1962) used storm water outlets to measure runoff from urban areas. Ree and Crow (1954) described a technique how to use rectangular highway culverts for the measurement of runoff volumes. Straub and Morris (1950) conducted

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[1]These ten conditions are listed in the Footnotes at the end of the chapter.

tests on corrugated metal pipe to arrive at calibration curves and hydraulic relationships. Herr and Bossy (1965) presented many capacity charts on the hydraulics of culverts. Holtan, Minshall and Harrold (1968) noted that, since culverts are simple and regular in form, and their hydraulic behaviour is well understood, they can be good runoff meters. Bodhaine (1969) gave a detailed account on methods which can be used for the measurement of peak discharges at culverts.

Culverts were selected as a supplementary technique for several reasons, including prior development, low expense, reliable measurement, known dimensions and hydraulics of flow. The problem of non-representativeness of a culvert was overcome in part by selection from numerous alternatives and by adjusting the gauging technique to certain conditions of flow. The corrugated steel culverts are widely distributed and used. Straub and Morris (1950); Neill (1962); Chow (1962); Holtan, Minshall and Harrold (1968), and others indicated that a culvert could be a good flow meter. Here then is a simple, relatively inexpensive flow gauging station already developed using the highway culvert as a measuring device.

From the aforementioned studies that dealt with the hydraulics of culverts, and others, it seems that it is very practicable to use them in hydrologic investigations. Mavis (1943) has shown that discharge through culverts flowing part full and with free outfall is dependent only on the upstream water-surface elevation. In this instance the relationship between depth of water above the culvert entrance and discharge rate is well defined and stable. Bodhaine (1969) presented tables, graphs and calibration curves on how to calculate peak discharge of culverts under six different situations. Thus, given the foregoing information, a single measurement of depth of water, either upstream or

downstream of the culvert ends, with a staff gauge is sufficient for determining the discharge rate.

Culverts having free outfall conditions are preferred for flow-rate measurements, but Bodhaine (1969) mentioned techniques which permit using culverts that are partially submerged or having other conditions. The majority of the culverts selected for this study had free outfall conditions.

Holtan, Minshall, and Harrold (1968) outlined five considerations for culvert selection.[2] These recommendations were followed in selecting sites where culverts were employed as gauging devices. In addition to clearly delimiting each plot, both the approach and outlet sections were cleared of any debris. The geometrical characteristics of each culvert were measured in order that established calibration curves and capacity charts could be employed for calculating the discharge values. The elevation of the water or head was read at the inlet sides of all culverts with the aid of a specially constructed staff gauge, calibrated in hundredths of a foot. This instrument was positioned at the base of the inlet end of the culverts as shown in Plate 2.

FIELD WORK AND DATA COLLECTION

The data for this study were collected during the period of spring 1971 to and including the spring of 1972. Many excursions into the field area were conducted to gather data, to maintain a watch on changing conditions and to check the weir and culvert sites. Final investigations were completed at the end of the snowmelt runoff period, 1972.

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[2] These five considerations appear in the Footnotes at the end of the chapter.

PLATE 2

Plate showing the writer positioning the hand-held staff gauge at the inlet to a culvert. This 24 inch culvert is located at the northwest corner of the Edmonton International Airport. The photo was taken on March 26, 1972 at a time of declining flow.

The runoff data from 3 weir sites and 10 culvert sites were collected during the spring (March - May) of 1972. Measurements were taken manually, but due to the distances between sites and the time required to drive from site to site, and time required to position the hand-held staff gauge at the culvert sites, readings were not made on as regular a basis as desired. The problem was overcome however during the initial runoff period, by taking more readings of the sites for the purpose of establishing diurnal patterns of runoff. Other problems were also encountered in the collection of runoff data. Obstruction of weirs, culverts, stilling ponds and drainage channels by ice and snow drifts was a significant problem. Initially all sites (weirs and culverts) had to be cleared of snow and ice so that the water could run freely. During each visit when readings were made, the ice or snow that had accumulated, especially after colder weather, snowfalls or heavy drifting, was removed. All the gauges were non-recording ones and only spot readings were taken, thus the accuracy of measurement was not affected if time was allowed for the re-establishment of flow patterns.

During the runoff period, lasting from the end of March to the beginning of May, several water samples were collected from the selected sites and also from the main creek. Chemical analyses were performed on these to determine any relationships between land use and quality of water. A HACH engineer's portable water testing kit (Model DR-EL) was used for such chemical determinations as Chloride, Phosphate and others.[3] The results of this procedure are tabulated and discussed

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[3]The explanation of HACH is given in the Footnotes at the end of the chapter.

in chapter four.

Several soil samples were also taken for soil moisture determination just before freeze-up in October, 1971. Samples were gathered and transported in air-tight plastic bags to prevent moisture loss. Samples were first weighed in their original condition, then oven-dried at 105 degree Centigrade and reweighed, the difference being the water content. The soil moisture conditions are discussed in chapter three. Additional soil moisture information was obtained from the Ellerslie farm research station operated by the Soil Sciences Department, University of Alberta.

DATA CONVERSION

The runoff data which are collected in the field are in the form of hundredths of a foot of head through 90 degree V-notch weirs and culverts. These readings cannot be used on a comparative basis and must be converted to cubic feet per second (cfs). This is accomplished by either using the Cone formula which has been empirically derived from standard 90 degree V-notch weirs, or using calculated tabulated values of discharge for the same weirs.[4] For the culverts, the runoff values were calculated from existing rating curves, from Herr and Bossy (1965), for specific culvert hydraulic relationships.

For the purpose of this study, most data were expressed in cubic feet per second, although at times small volumes of flow were involved. By expressing the data in these units other steps of data

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[4]The Cone formula appears in the Footnotes at the end of the chapter.

manipulation and conversion were avoided. Once the data had been converted to a useable form, they were plotted on hydrographs on an hourly basis. Once the flow volumes were calculated, they were totalled to obtain volumes of discharge for the entire runoff period. Discharge volumes in cubic feet per second were then converted to area inches of surface runoff for each site on both daily and total runoff period basis. This conversion to inches of runoff allowed direct comparison between sites by removing the variations in volume caused by differences in area. Patterns of runoff obtained for the plots are discussed in chapter four.

FOOTNOTES

[1] These ten conditions are as follows:

1) The upstream face of the bulkhead (dam) should be smooth and in a vertical plane perpendicular to the axis of the channel.
2) The upstream face of the weir plate should be smooth, straight, and flush with the upstream face of the bulkhead.
3) The entire crest should be a level, plane surface which forms a sharp, right-angled edge where it intersects the upstream face. The thickness of the crest, measured in the direction of flow, should be between 0.03 and 0.08 inch (about 1 to 2 mm).
4) The upstream corners of the notch must be sharp. They should be machined or filed perpendicular to the upstream face, free of burrs or scratches, and not smoothed off with abrasive cloth or paper.
5) The downstream edges of the notch should be relieved by chamfering if the plate is thicker than the prescribed crest width. This chamfer should be at an angle of 45 degrees or more to the surface of the crest.
6) The distance of the crest from the bottom of the approach channel (weir pool) should preferably be not less than twice the depth of water above the crest and in no case less than 1 foot.
7) The distance from the sides of the weir to the sides of the approach channel should preferably be no less than twice the depth of water above the crest and never less than 1 foot.
8) The overflow sheet (nappe) should touch only the upstream edges of the crest and sides, so that air can circulate freely both under and on sides of the nappe.
9) The measurement of head on the weir should be taken as the difference in elevation between the crest and the water surface at a point upstream from the weir a distance of four times the maximum head on the crest.
10) The cross-sectional area of the approach channel should be at least 8 times that of the overflow sheet at the crest for a distance upstream from 15 to 20 times the depth of the sheet.

[2] The five considerations for culvert selection are:

1) Culvert has simple cross-section with special entrance.
2) Culvert has steep or gradual barrel.
3) Culvert has free discharge at outfall evidenced by drop or scour hole at outlet.
4) Culvert has sufficient capacity to pass maximum flood flow.
5) Culvert has satisfactory approach conditions.

[3] HACH is the name of a U. S. Company that manufactures several types of portable testing kits for determination of chemical constituents and their concentrations in water.

[4] Cone formula: $Q = 2.49H^{2.48}$

where Q = discharge over weir in cfs

H = head on the weir in feet

From Water Measurement Manual, U. S. Department of the Interior, Bureau of Reclamation, 1971, p. 24.

CHAPTER II

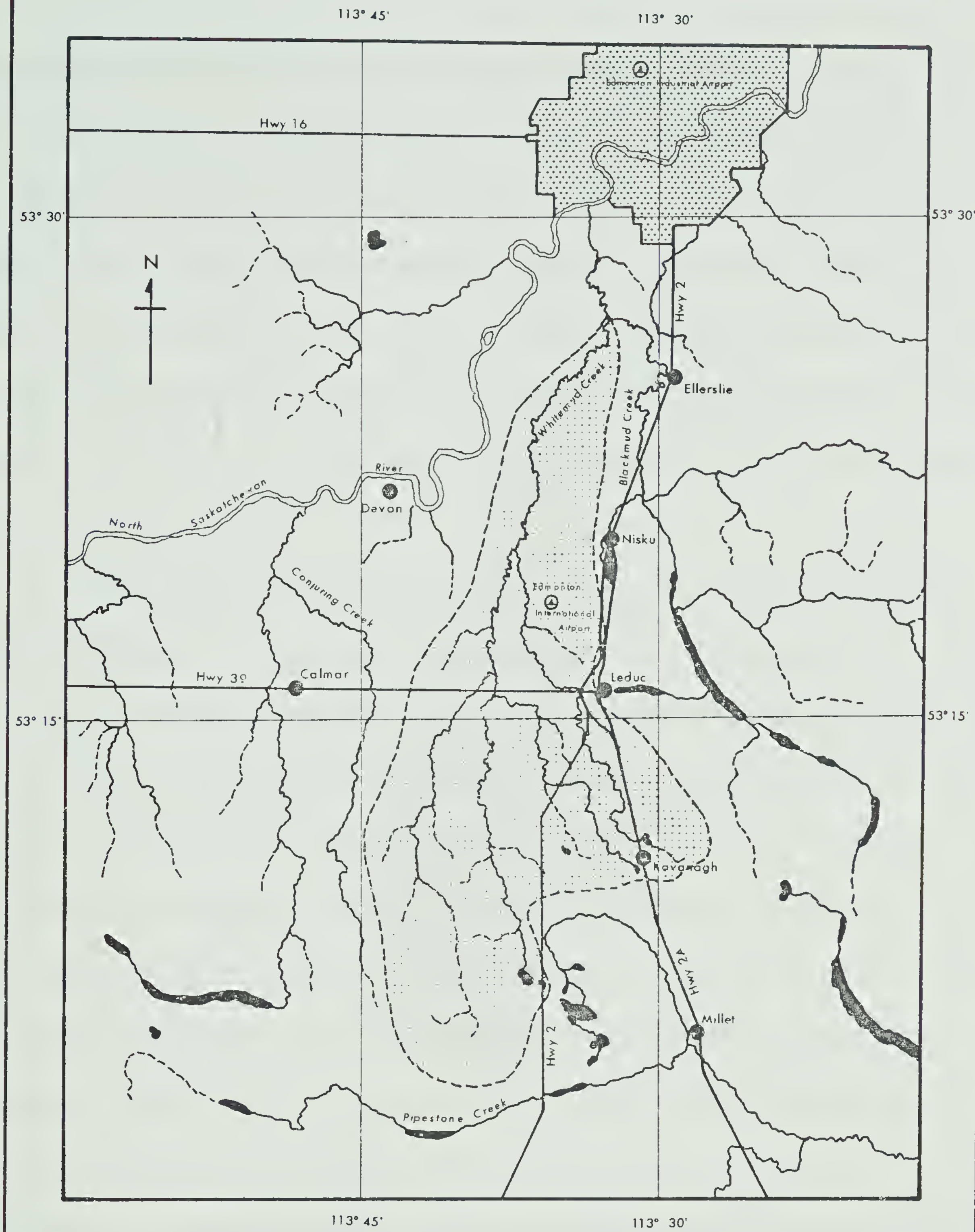
PHYSICAL CHARACTERISTICS OF THE WHITEMUD CREEK BASIN

The purpose of this chapter is to describe the various physiographic, hydrologic and climatic characteristics of the Whitemud Creek Basin and discuss how these may affect the local surface runoff patterns.

GENERAL CHARACTERISTICS

The basin, comprising an area of approximately 142 square miles, lies directly south of the city of Edmonton. The basin occupies parts of three counties (Strathcona, Leduc and Wetaskiwin). From the confluence of the Black- and Whitemud Creeks, it extends for a distance of approximately 22 miles to the drainage divide with the Pipestone Creek. Its eastern limits coincide roughly with Highway 2, but these limits vary south of Leduc, and its western limit is the Conjuring Creek Basin divide. The study area lies between 53 degrees and 53 degrees 30 minutes north latitude, and 113 degrees 25 minutes and 113 degrees 45 minutes west longitude. The general shape, location and extent of the basin are illustrated in Figure 1.

Topographically the study area does not have great relief, varying from 2,100 feet elevation near the mouth of the creek, to approximately 2,600 feet above mean sea level in its headwaters. In a north to south direction from the mouth to the headwaters, the



LOCATION OF THE WHITEMUD CREEK BASIN

0 1 2 3 4
miles

Bosin Divide

Bosin

Town

Road

Lake, Pond, Slough

Droinoge

Figure 1

Source: NTS mop Scole 1:250,000

physiography of the basin varies slightly from level to gently undulating land. In the south the depressions (swales) are deeper and more of these have enclosed drainage systems in most years. The level terrain is broken by Whitemud Creek which has eroded a noticeable valley into the surficial materials and bedrock outcrops occurring in the study area. There are also numerous smaller streams, roadside and other drainage ditches, in addition to the main channel, which assist in draining the basin.

The study area is characterized by a continental climate having relatively warm summers and cold winters. The mean summer temperature, May to September inclusive, is 56 degrees Fahrenheit and the mean winter temperature, October to April inclusive, is 16 degrees Fahrenheit. Detailed long-term meteorological data for the Edmonton area and some analyses of these are contained in an annual summary report issued by the Dominion Public Weather Office, Edmonton. Other more general analyses of climatic data were performed by Longley (1967) for climate and weather patterns of Alberta; Muttitt (1961) for spring and summer rainfall patterns in Alberta; Kendrew and Currie (1955) for the climate of central Canada and many others. More specifically, several studies have been and are being conducted in the basin. Rains (1969) referred to the climate of the basin, White (not completed) on the snow accumulation pattern in the basin, Whistance-Smith (not completed) on rainstorm intensities and paths over the basin, and the writers study on runoff patterns.

The average annual temperature of the study area is 36.5 degrees Fahrenheit, and the average annual precipitation is 17.67 inches. Approximately 73 per cent of this precipitation or 12.37 inches falls as

rain, the remaining 27 per cent or 5.30 inches, falls as snow, largely after the ground has been frozen.

VEGETATION CHARACTERISTICS

The existing vegetation in this, as in other regions, is markedly controlled by the moisture balance characteristics. The vegetation can thus provide a good indication of the variable water balance patterns within an area. These variations in turn will reflect differences in surface runoff and subsequent streamflow.

The natural vegetation of the area is that of aspen parkland, transitional to boreal mixed forest (Bird and Bird, 1967; La Roi, et. al., 1967). Moss (1955) described the region within which the basin is located, as a zone where both the true prairie grassland and poplar forest are present. The parkland area is dominated by Chernozemic Soils which suggests that it formed under a grass vegetation (Moss, 1955). He suggested that, as a result of climatic changes and possibly periodic burning, groves of aspen poplar were established in comparatively recent times. Bowser, et. al., (1962) postulated that the salt in Solonetzic Soils would be a deterrent to the establishment of tree growth. The areas of Podzolic Soils were considered by Moss (1955) to be linked with a dominant aspen poplar vegetation, along with balsam poplar. The aspen is thought to be the more dominant type in the parkland, since this species favours slightly drier sites than the balsam (Bowser, et. al., 1962). Many other plant species are also present including shrubs, grasses, herbs and mosses for example.

Wherever vegetation grows, it removes water from the soil, and through its roots and organic matter affects the movement and storage of

water. In turn, wherever streamflow or runoff tends to occur, it is the result of the interactions of a number of factors of which soil and vegetation are significant ones. Streamflow provides useful indicators of net results of land use practices. The streamflow changes can be described in terms of total yearly amount of flow, seasonal regularity frequencies, extremes of high and low discharges, quality and other means.

Since the coming of the first settlers into the area, man's activities have increasingly altered the natural environment and considerably affected the vegetation. The main result of man's continuing interference, with vegetation in particular and the environment as a whole, has caused alterations in the natural water balance and runoff patterns. This subsequently has given rise to variations in streamflow characteristics.

Over one-half of the defined area is now under cultivation, but there are still forested parts which have undergone relatively few changes, that permit an assessment of the type of vegetation that was present when settlement of the area began. These woodplots become more numerous as one proceeds from north to south through the basin.

All the remaining "natural" vegetation in the wooded areas may have been altered by man or other agents. Such areas within the basin tend to have distinct water balance patterns. The bush plots of this study aid in the evaluation of how significant plant cover is to snowmelt runoff in the basin. They may also assist in indicating the type of melt conditions when the basin was more forested.

TOPOGRAPHICAL CHARACTERISTICS

Whitemud Creek Basin does not have very much surface configuration. The main creek falls more than 500 feet over a distance of approximately 24 miles. This amounts to a drop of about 21 feet per mile. The terrain through which the drainage channels pass varies from level prairie, being largely a lacustrine plain in the north, to gently rolling land of a bevelled till plain in the middle portions. The basin becomes more hilly in parts of the headwaters in the south, which is composed of a more undulating till plain. Rains (1969) discussed in some length the variation of slopes and east-west cross-profiles of the basin from south to north. The writer feels that it is not necessary to repeat what has already been analyzed in the previous study.

The drainage basin is oriented in a south to north direction, that is, the water flows from the hilly headwaters in the south to the more level plains in the north. One of the objectives of this study is to examine the effect of aspect on surface runoff, to discover whether there are significant differences in the study area due to this variable. Aspect though, is particularly common in the narrow stream valleys. It is particularly noticeable in the lower valley where slopes are steep as a result of stream incision into the plain. Thus aspect may prove to be of minor importance to runoff patterns in this area. Landals (1970) in his Pocket Lake study near Yellowknife in the Northwest Territories, discovered some variation in quantity and timing of runoff from north- and south-facing slopes. The U.S. Army Crops of Engineers (1956), in their report on Snow Hydrology, mentioned that orientation of a basin is important because it has an effect on:

1) the accumulation of precipitation
2) the snowmelt rates

Other factors contributing to variations in snowmelt runoff are differences in geology, surficial deposits, soils and vegetation, climate and also various types of land use. Some of these will be discussed in the following sections. One reason why different runoff patterns result can be attributed to the variations in albedo of different surfaces.

DRAINAGE CHARACTERISTICS

The basin has a dendritic drainage pattern. There appears to be one predominant channel, the Whitemud Creek itself, which carries the major flow of water. From the confluence of the Blackmud and Whitemud Creeks, the streams follow a single valley for approximately five miles and enter the North Saskatchewan River. In this lower course the stream passes through established and expanding suburban areas of Edmonton.

Only the main stream has eroded a very distinct valley into the surficial deposits of the study area, especially in its lower course. In addition to the main stream,there are also numerous smaller streams, ditches and grassed waterways which assist in draining the basin. The drainage density and network are physical characteristics influencing the ease with which an area is drained of water. These characteristics also influence the timing of runoff, that is,how quickly and efficiently surface runoff is drained from a particular basin.

The drainage density, which is the average length of streams per unit area within the basin, is high for the climate because of the relatively fine surficial materials. Consequently the drainage efficiency of the basin is high because there are relatively few deep depressions

that retain runoff. In addition the channels are relatively straight down valleys which tend to be quite regular in profile (see Figure 2 showing drainage and topographical characteristics of the basin). The headwaters have a less efficient drainage network than either the middle or the lower portions of the basin. Rains (1969) evaluated the basin's fluvial geomorphology. He concluded that it was a typical fourth order basin with respect to area/channel length properties of the local region.

The basin can in fact be divided into three convenient sections:

1) A headwater region of gently rolling terrain containing a number of low depressional areas, sloughs and many wooded areas. Throughout this sub-region a variety of land use occur, from hay and pasture fields for cattle, to the growing of grain crops. The cultivated fields of this region appear somewhat scattered due to the presence of poorly drained depressional areas and forested plots. The region has a number of sloughs that act as local or internal catch-basins, and some of these only contribute runoff in very wet years. The stream channels in the region are not well defined. They pass through low marshy areas, and from one slough to another without good channel definitions.

2) A middle region of relatively level land containing mostly cultivated lands (pastures and crops). A variety of land use is also present as in region one. The cultivated fields are more continuous, and not as broken as in region one. Scattered brush plots and bush adjacent to drainage channels provide a break in the field patterns. The Edmonton International Airport is located along the eastern

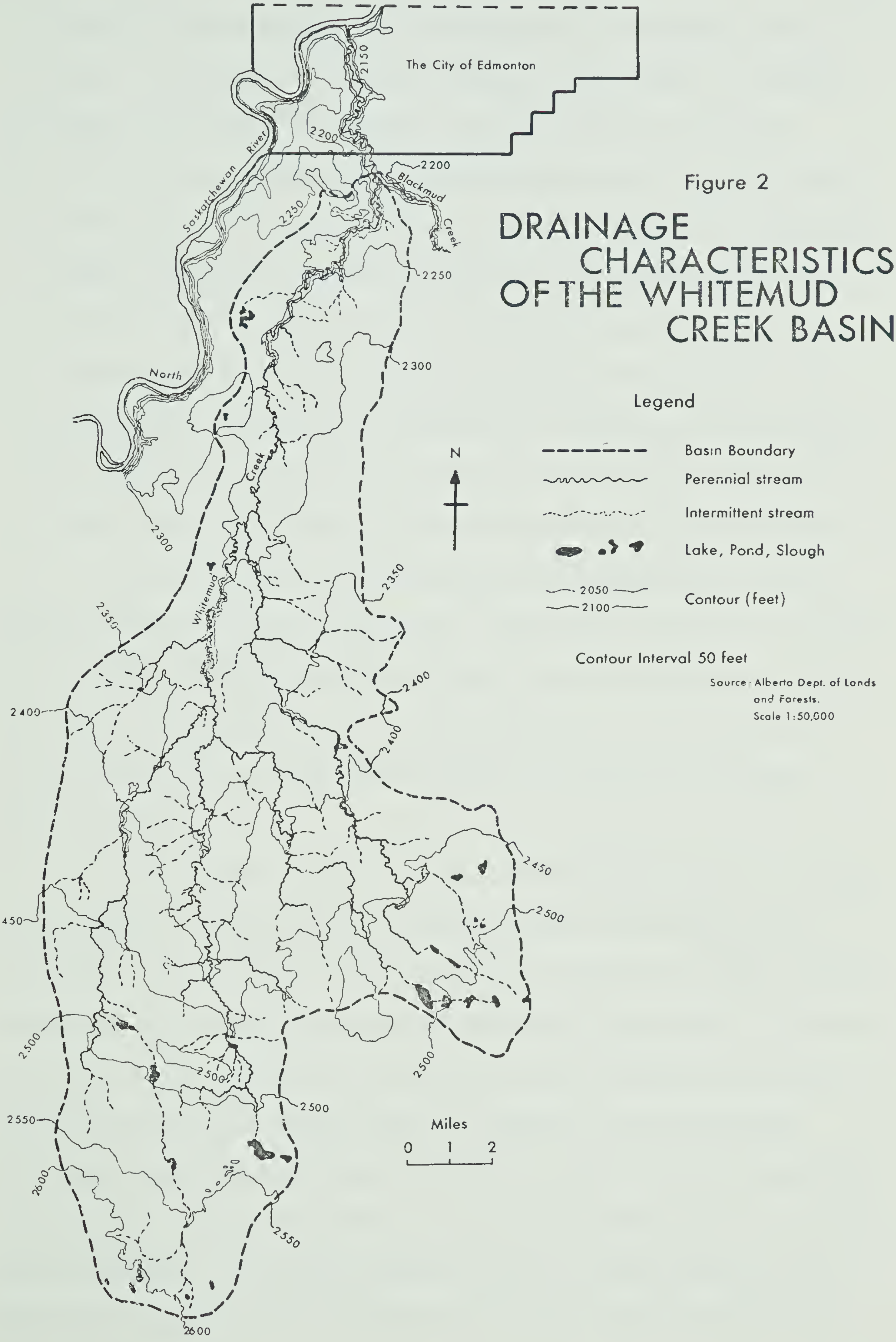


Figure 2

DRAINAGE CHARACTERISTICS OF THE WHITEMUD CREEK BASIN

boundary of this region. It accounts for a considerable land use area. The channels are better defined in this region. They have eroded discernible drainageways into the surficial materials.

3) A lower region of level terrain with interspersed kame-like hills. This region of the basin is extensively cultivated. It contains the deeply incised main channel of Whitemud Creek which provides the only major break in the terrain. The main land use in the lower course of the creek is for urban and recreational purposes. In the intensely urbanized areas adjacent to the lower stream course, the local channels are often artificial ones. These collect the urban runoff and direct the water into the main natural channel.

Some difficulty was encountered in distinguishing certain channel reaches as definite channels. Many small tributaries, especially in the headwaters consist merely of broad grassed waterways and swales. They play an important role in collecting water and contributing the concentrated runoff to the basin's channel system under favourable moisture conditions.

The drainage conditions throughout the basin have been altered considerably in historic times by natural events, human and animal activities. Such changes as the creation of artificial drainage ditches contribute concentrated runoff quite efficiently and quickly to natural channels. The installation of culverts to direct flowing waters, the creation of the International Airport, changes in land management practices, and other developments within the basin have all contributed to significant changes in runoff patterns and to variations in streamflow characteristics. By further examining several of these aspects in the following chapters, it is illustrated how these land use changes have

been operative in modifying the runoff patterns.

SOILS

Soils in any area are usually the product of several factors and processes. These factors are climate, geology (parent material), slope,biologic organisms (plant and animal), time and drainage. The presence of a well-developed soil, or the lack of such, plays an important role in the moisture balance patterns of an area. The soils of any region are relatively important in the analysis of a basin's water balance computations because they serve as a storage reservoir for any water that infiltrates. Soils influence the rates of infiltration, percolation, water retention capacity and plant-moisture relationships. Cole and Machno (1969) reported that the soil system plays a critical role in the water balance because it regulates rates of water percolation, utilization and storage.

The moisture content in any soil varies during the course of the year under the influence of precipitation, runoff, evapotranspiration and drainage (Verma, 1968). Runoff may occur in the basin, but depending on a number of factors such as infiltration rate, soil moisture, slope and others, the chances for runoff actually occurring are small. This is especially true for summer rainfall. With respect to the areal extent of the basin, it seems unlikely that soil moisture storage is distributed uniformly, consequently variation in runoff arises. Laycock (1962) noted that runoff can occur on clays, frozen soil, and steep slopes long before soil moisture retention capacities have been reached.

Many studies concerned with moisture balance patterns have been conducted. Some of these were performed with special emphasis on

the determination of potential evapotranspiration. Studies done by Laycock (1967) on water deficiency and surplus patterns in the prairie provinces, employed the Thornthwaite procedure for estimating potential evapotranspiration. In the studies he assumed a wide range of available water capacity. The moisture deficits which would likely occur under the varying water capacity conditions were then calculated.

Mather (1959) indicated that, if the amount of precipitation is always greater than evapotranspiration, the soil remains above field capacity and water surpluses are continuing. When rainfall or snowmelt infiltrates into the soil, it is stored within the soil profile replacing the soil moisture that had been withdrawn for evapotranspiration. Once the soil has been filled to field capacity, any surplus water will be lost by surface runoff or groundwater recharge.

The report on Snow Hydrology by the U. S. Army Corps of Engineers (1956) indicated that the soil functions as a reservoir, storing water when available to be used during periods when the potential evapotranspiration exceeds current supply. The report also mentioned that under average conditions, the depth of water stored as soil moisture available for use is about four inches. Penman (1963) believed that the amount of water stored in the soil for use by plants is largely limited by soil characteristics.

The average runoff which occurs, and the ratio of runoff to precipitation reflect such variables as the seasonal changes in soil properties and their effect on the hydrological characteristics of small drainage basins (Verma, 1968). Schiff and Dreibelbis (1949) concluded that soil properties and land use principally account for differences in hydrologic performance. In his study of moisture balance in soils of

the Edmonton area, Verma (1968) concluded that there is a very small chance for the occurrence of runoff. This is correct if one assumes distribution of precipitation that corresponds fairly closely to potential evapotranspiration. This pattern does not prevail in the basin, and the variations in it provide most of the surplus water.

A number of different soils having variable physical characteristics, moisture content and ability or potential for soil moisture recharge are present in the basin. These characteristics together with other properties influence the amount of runoff, and differences in runoff patterns appear. Depending on the foregoing conditions, runoff may or may not take place. Verma's conclusion was based on a comparison of rainfall intensities of summer storms with corresponding infiltration rates. He was concerned with soils and did not consider the variable land use that exists in the area. Rainfall intensities do, at times, exceed the infiltration capacities, especially in the parts of the basin covered by airport runways and paved highways. The properties of these surfaces are such that little water infiltrates and seeps downward. Most of it is detained for surface flow on the relatively impermeable surfaces. A storm of short duration and low intensity may produce some runoff from such areas. Similarly other areas have seasonal or occasional surpluses for various reasons to be discussed.

Soil thicknesses in the study area are variable, but generally are fairly deep. Bowser, et. al.,(1962), in the Soil Survey of the Edmonton Sheet, discussed the types of soils that are present in the region. Those that are present in the basin are mapped on Figure 3. These include Chernozemic Soils developed on lacustrine material, Solonetzic Soils developed on glacial till and residual material,

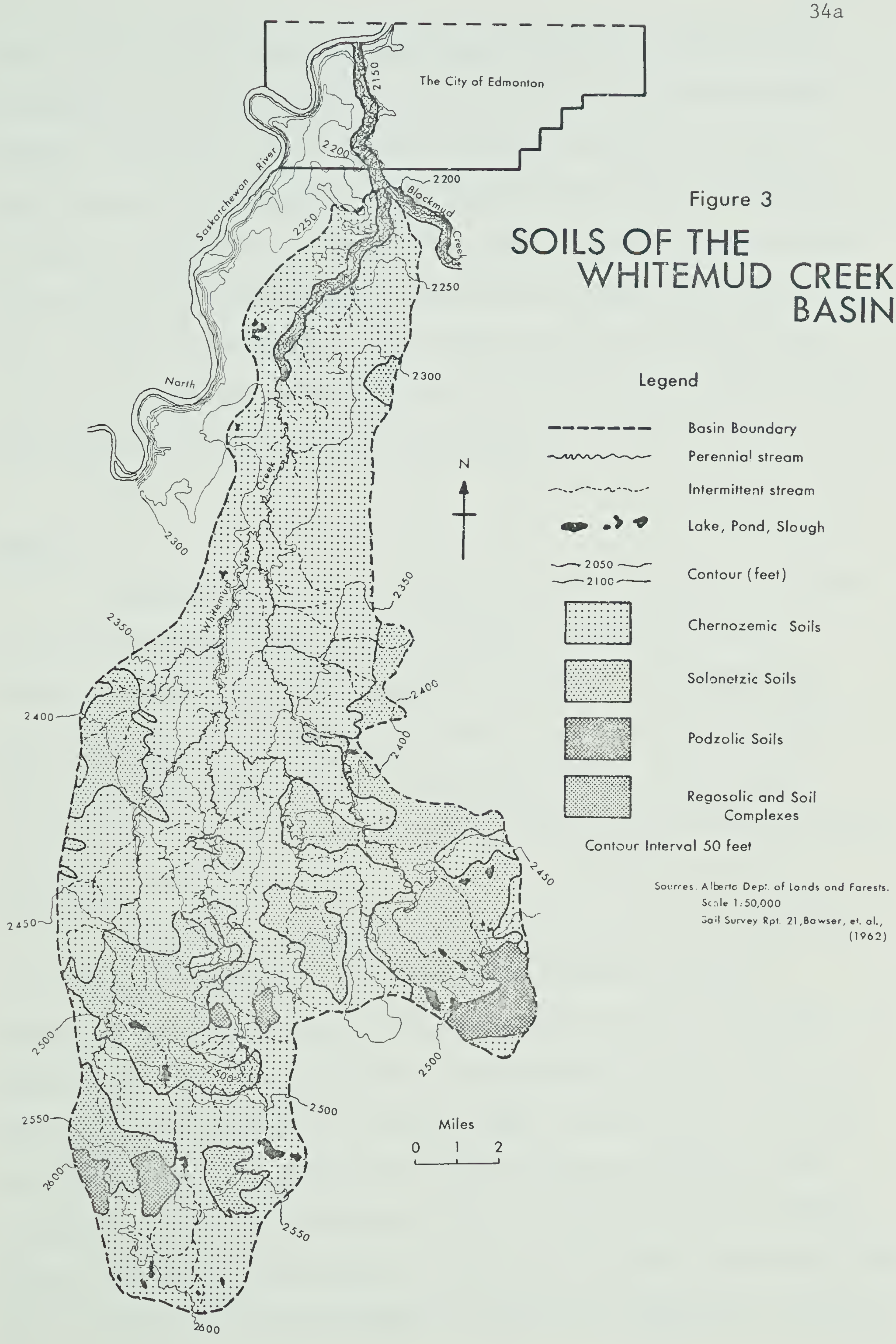


Figure 3
SOILS OF THE WHITEMUD CREEK BASIN

Podzolic Soils of the Dark-Grey Wooded type developed on glacial till, and Regosolic Soils of alluvium developed on recently deposited stream material. Generally, the Chernozemic and Podzolic Soils of the area have a relatively good permeability. The Solonetzic Soils, though, may be somewhat impermeable due to the development of a hard, compact, clay-rich sub-soil layer which inhibits infiltration (Toogood and Newton, 1955). Schiff and Dreibelbis (1949) believed that no matter what the type of soil, the small differences in the rates of water movement therein were related to land use practice differences.

GEOLOGY

Slaymaker and Jeffrey (1969) described how climate and geology influence the stream regime and water quality. Within any area the hydrologic characteristics are largely determined by the geology and also the climate of the area. The climate of the basin will be dealt with in the next section, but now the salient features of the basin's geology will be examined concerning how they are related to the hydrologic conditions of the area.

The basin is underlain by Upper Cretaceous bedrock consisting of the Edmonton Formation, a brackish water formation composed of bentonitic sandstones, sandy shales, bentonitic clays and coal seams (Ower, 1958). This formation has a low permeability and thus is a poor source of groundwater. Le Breton (1963) indicated that its yields from wells in it were commonly less than 5 gallons per minute. The transmissibility of the formation is also low varying from less than 60 gallons per day per foot (gpd/ft) to less than 100 gpd/ft (Le Breton, 1963). Due to the foregoing characteristics, the Edmonton Formation is considered

to have a poor capacity to absorb infiltrating waters. A more important feature is in the lack of recharge of this formation. The transmissibility is sufficient to maintain a relatively strong flow in the creek throughout the year, but this is not present. Although discharge from springs and seepage occurs more in the lower course and in the North Saskatchewan river valley, they do not sustain a base flow. This is small and there is almost no continuing base flow in the creek above the Whitemud and Blackmud Creek junction. Thus one could assume that the bedrock geology, insofar as groundwater discharge is concerned, does not play a significant role in the streamflow in this basin. Another reason for the lack of base flow is the presence of relatively impermeable surface clays combined with the limited surplus water for percolation.

The bedrock topography has been mapped by Farvolden (1963a). He also indicated the presence of several pre-glacial valleys that are at a lower level than the present creek valley. Apparent transmissibility within these pre-glacial valleys is also considerably higher (approximately 2,000 gpd/ft) than in the Edmonton Formation. Insomuch as the bedrock topography is concerned, it has been a determining factor in partially controlling the present surface configuration.

The deposits which influence runoff to a marked degree are the unconsolidated materials overlying the bedrock. Most of the surficial deposits in the area are materials derived from the action of glaciers. The materials of central Alberta as a whole, and of the Edmonton region specifically have been studied by several workers. They have proposed hypotheses on source areas for the deposits (Tyrrell, 1886; Antoniuk, 1954), on the direction of ice movement (Rutherford, 1928; Gravenor and Bayrock, 1961), and on the geological history and depositional sequence

(Duff, 1951; Bayrock and Berg, 1966; Rains, 1969; Keeble, 1970). The surficial materials are mapped on Figure 4. It is evident from this Figure that glacial lacustrine deposits are fairly extensive. These sediments together with the other deposits have an effect on the variations in the runoff patterns of the study area. All the different materials have variable structure, texture, composition, porosity and permeability, infiltration and percolation rates and different storage capacities, and also slightly different vegetation. The lacustrine deposits for example are composed of fine materials, are relatively porous and permeable and have a high storage capacity. The tills on the other hand have a mixed composition, have low porosity and permeability and also have low storage capacity. Although the foregoing are only general relationships they still all interact to produce the variable patterns of runoff.

CLIMATE

In any water balance study, an understanding of climatic relationships is essential. The snowmelt runoff patterns in an area depend upon climate since it is responsible for the amount of water in the snowpack and controls the rate of release of this water in the spring. The examination of long-term climatic records of primarily temperature and precipitation are necessary for the analyses of surplus, and subsequent runoff patterns. Some factors affecting temperature include latitude and the duration of sunshine. Precipitation in the form of rain and snow provides amounts of water available for processes such as evaporation, transpiration, runoff and storage increase. It is thus a fundamental component in water balance evaluation.

The meteorological stations that were selected for analyses

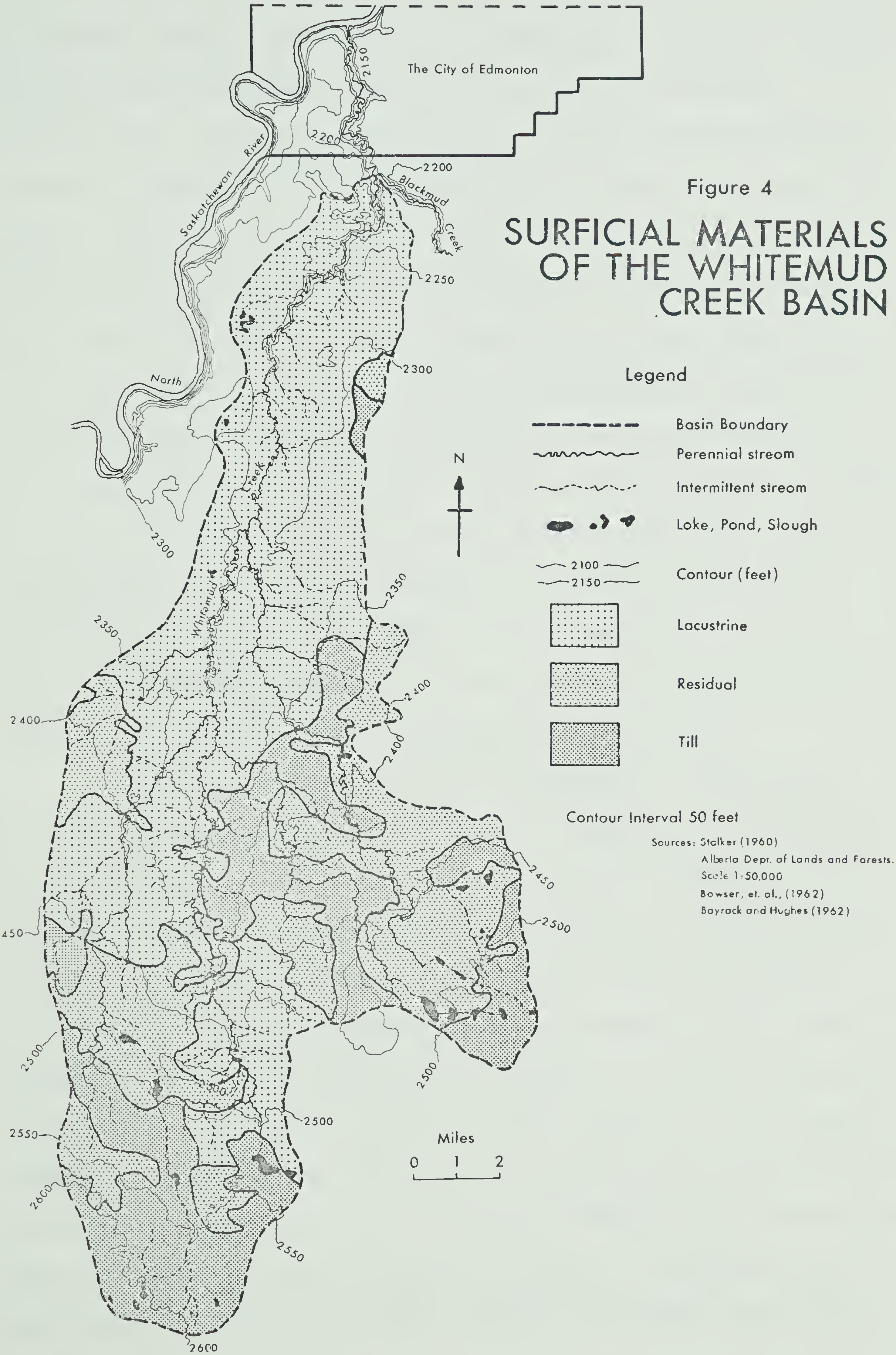


Figure 4

SURFICIAL MATERIALS OF THE WHITEMUD CREEK BASIN

of long-term climatic trends included the Edmonton International Airport, Edmonton Industrial Airport, Calmar and the University of Alberta Ellerslie Farm. The locations of these and of other instrumentation are indicated on Figure 5. The choice of stations was based upon length of observed record at the individual stations, and their geographic location with respect to the basin. The data from these stations, when applied to the basin, represent as closely as possible the climatic conditions of the study area. This though, is based on the assumption that the data recorded at each station are reasonably correct and representative of the surrounding area. The data from these stations, (long-term averages of temperature and precipitation), were used for computations of water balance using the Thornthwaite procedure. The record of the Edmonton station is used throughout from 1883 to 1972. From 1941 on, the data from this station are averaged with the data from the other mentioned stations. The data were used in this form for all analyses.

The climate of the study area is continental, characterized by relatively warm summers and cold winters. Representative temperature and precipitation data for the basin are illustrated in Figures 6 and 7. The average annual temperature for the area, as shown by Figure 6, taken from observations over an 89-year period, is 36.5 degrees Fahrenheit. The mean summer temperature, May to September inclusive, is 55.9 degrees Fahrenheit. July is the warmest month, averaging 61.8 degrees Fahrenheit. The mean winter temperature, November to March inclusive, is 15.4 degrees Fahrenheit. January is the coldest month, averaging 6.2 degrees Fahrenheit. Extreme winter lows may fall below -40 degrees Fahrenheit and extreme summer highs occasionally go above 90 degrees Fahrenheit. The month of April has a mean temperature of 40 degrees Fahrenheit and October 40.8 degrees

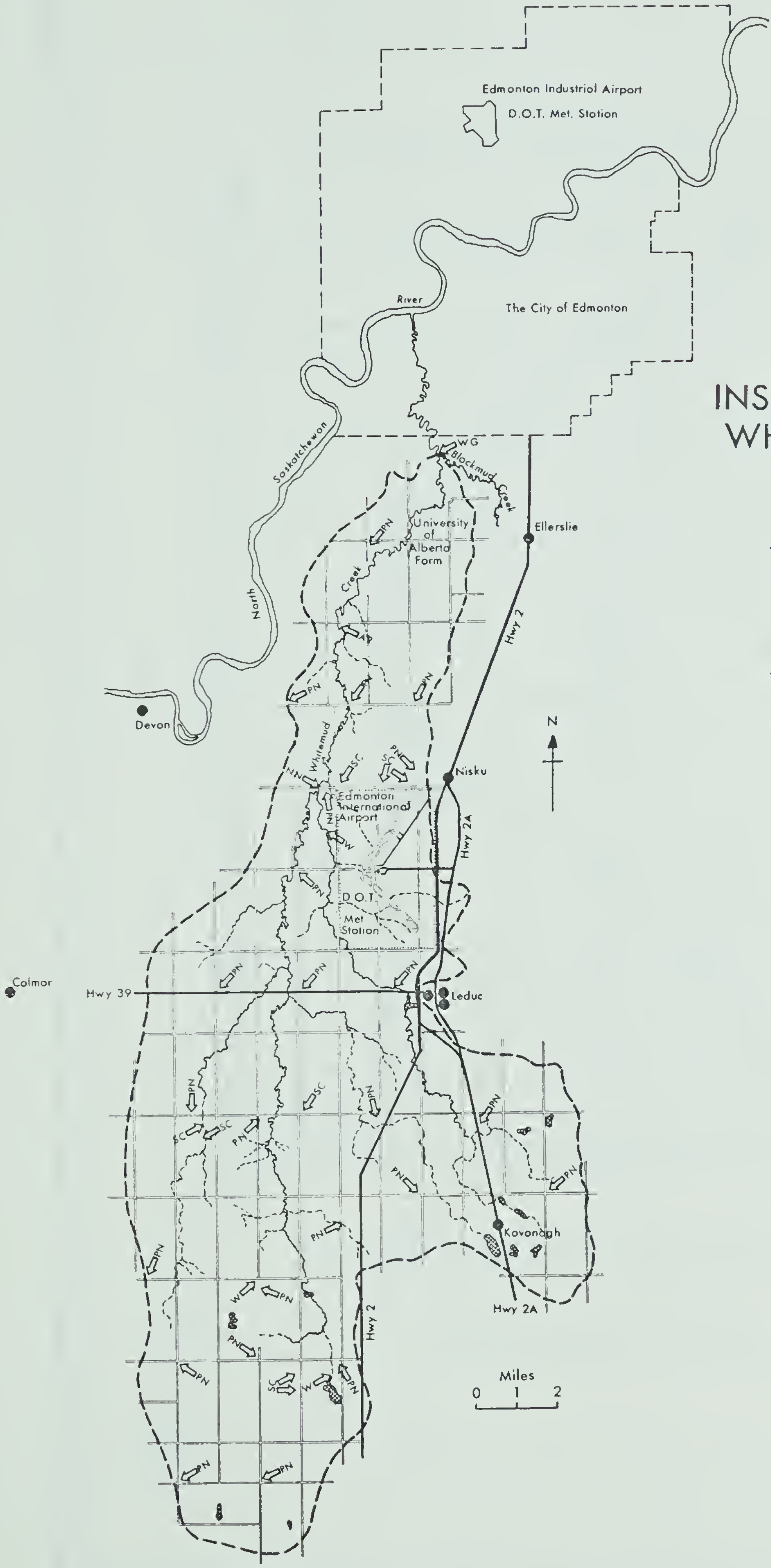


Figure 5

INSTRUMENTATION OF THE WHITEMUD CREEK BASIN

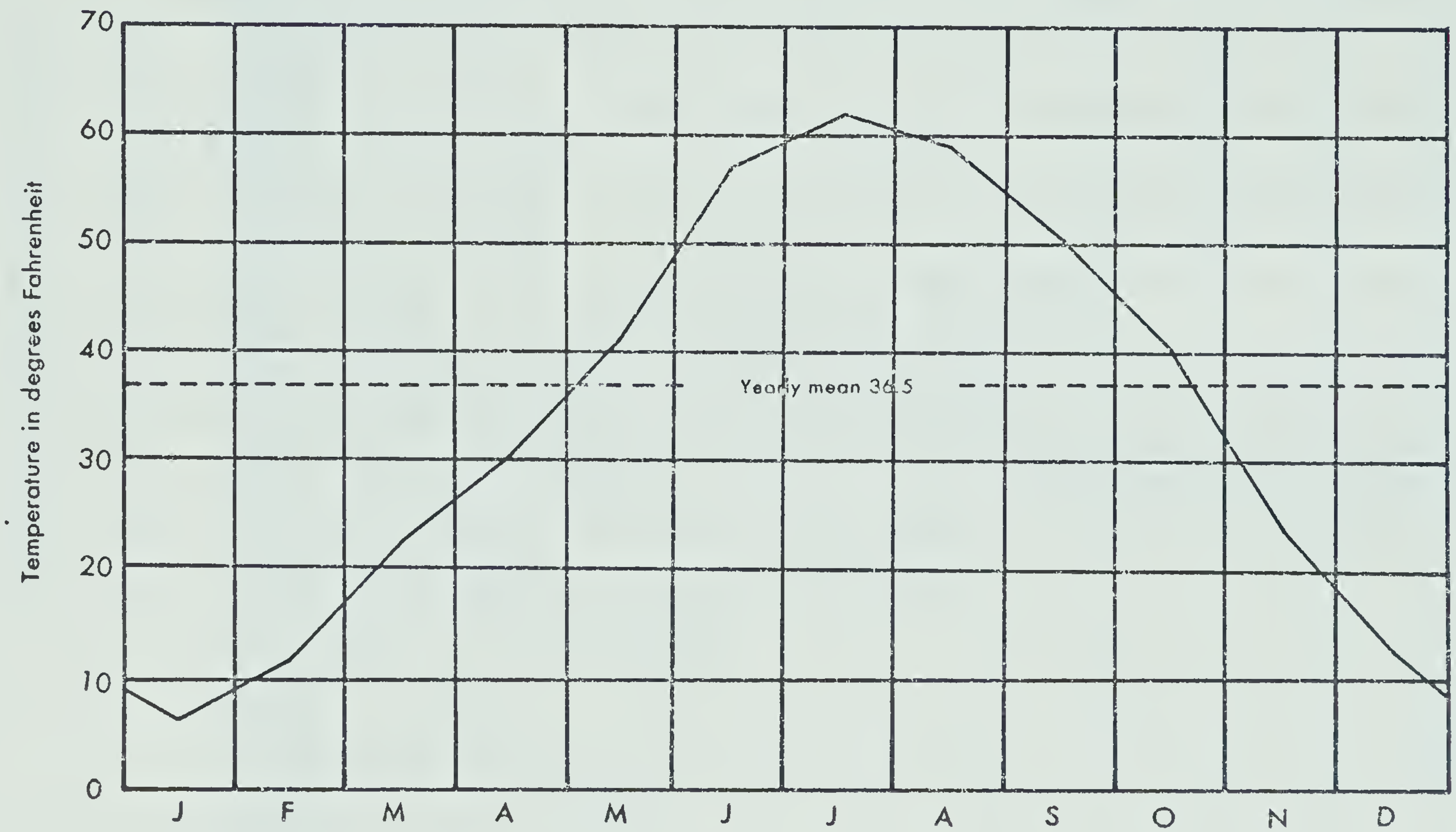
Legend

- Basin Boundary
- Perennial stream
- Intermittent stream
- Lake, Pond, Slough
- Highway
- Road
- Towns
- NN Hydrometric station, natural control, non-recording
- AR Hydrometric station, artificial control, recording
- WG Water level gauge
- W Weir location
- SC Snow course
- PN Precipitation gauge, non-recording

Sources: Alberta Dept. of Lands and Forests; Scale 1:50,000
Alberta Water Resources
Canada Water Survey
Ron Whistance-Smith

Figure 6

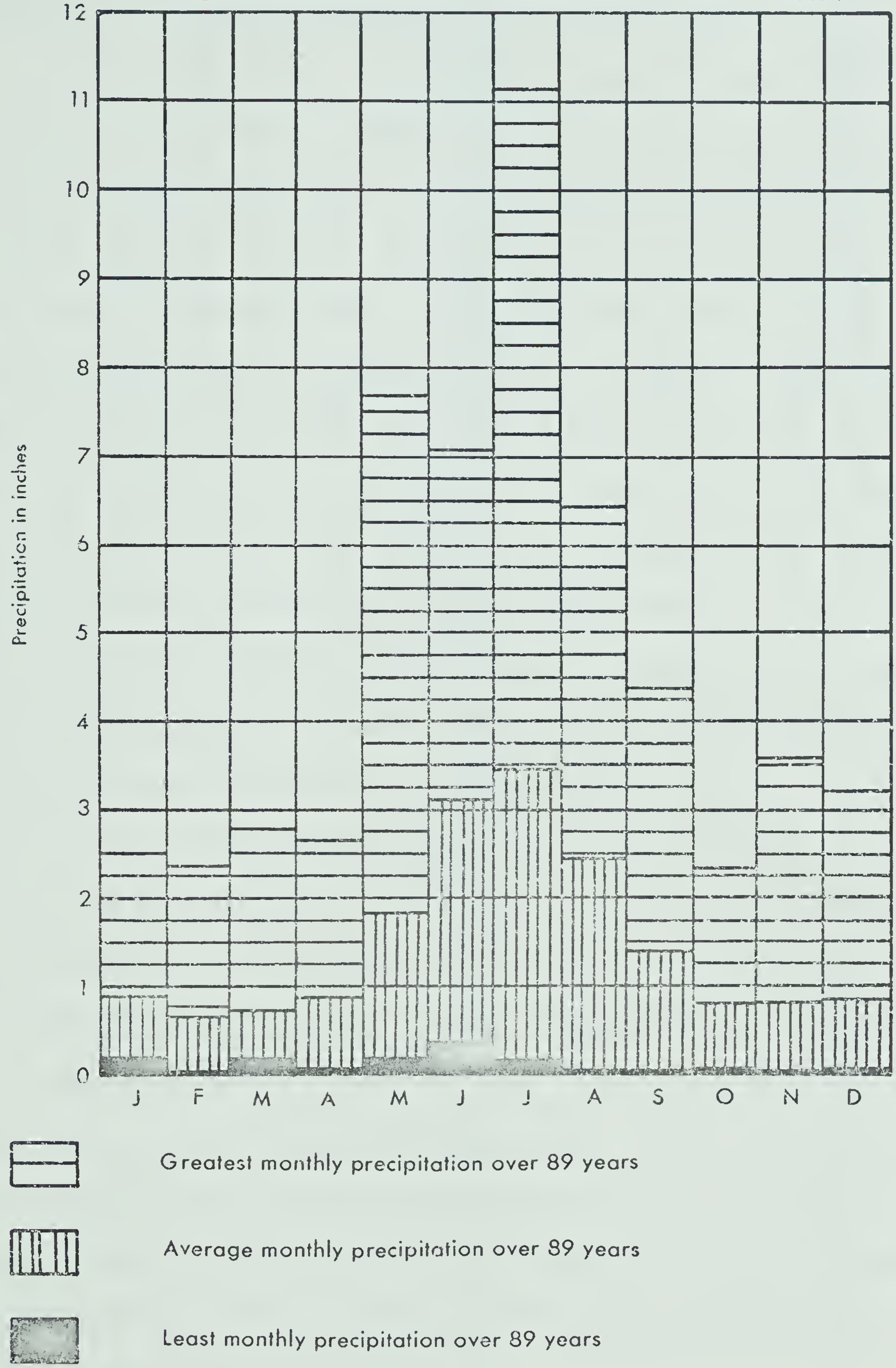
AVERAGE MONTHLY TEMPERATURE FOR WHITEMUD CREEK BASIN



Source: Annual Meteorological Summary, Edmonton:
Met. Div. Cdn. Dept. of Transport.
Averages of stations mentioned in thesis.

Figure 7

PRECIPITATION FOR WHITEMUD CREEK BASIN



Source: Annual Meteorological Summary, Edmonton: Met. Div. Cdn. Dept. of Transport. Averages of stations mentioned in thesis.

Fahrenheit. During 1971 the average temperature was 35.4 degrees Fahrenheit or 1.1 degrees Fahrenheit below the average.

The average annual precipitation, similarly taken from observations over an 89-year period is 17.67 inches, is shown on Figure 9. In 72 per cent of the years the total precipitation (rain plus snow) was between 14 and 21 inches. In 1971 the total precipitation was 16.82 inches or 0.85 inch below the average. The average monthly precipitation amounts to slightly less than 1.5 inches. June, July and August are the months of highest rainfall, totalling an average of 8.93 inches. The distribution of precipitation through the year for the 89-year period is illustrated on Figure 8. On examining this Figure the annual trend in precipitation becomes quite evident. It progresses from low values in January, February, March and April to higher amounts during May, June, July and August. July tends to be the month with the maximum amount of precipitation. In September, and through to December the precipitation drops again. Approximately 73 per cent of the precipitation falls as rain. This amounts to 12.37 inches of annual average rainfall. The remaining 27 per cent or 5.30 inches falls as snow, largely when the ground is frozen. The average annual snowfall in the study area amounts to slightly more than 50 inches, but this has varied from 9.2 inches during the winter 1888 - 1889 to 90.3 inches during the winter 1906 - 1907. October and April each receive an average of about 7 inches of snow in additition to some precipitation in the form of rain. The precipitation occurring during November to March is almost exclusively snow.

The rainfall occurring during the summer, as described by Toogood (1963), is generally low in intensity and well distributed over

Figure 8

MONTHLY PRECIPITATION TOTALS FOR WHITEMUD CREEK BASIN

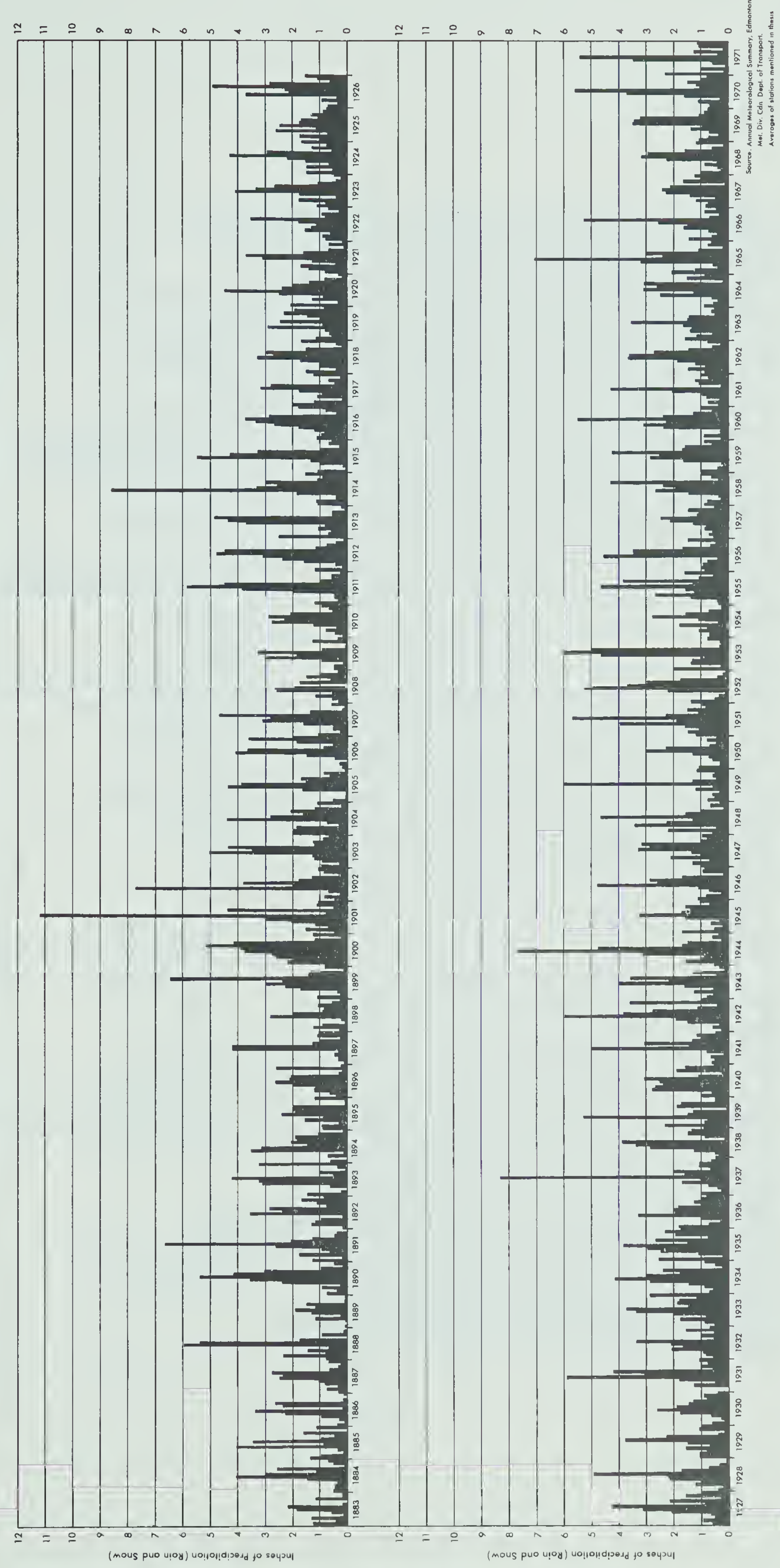
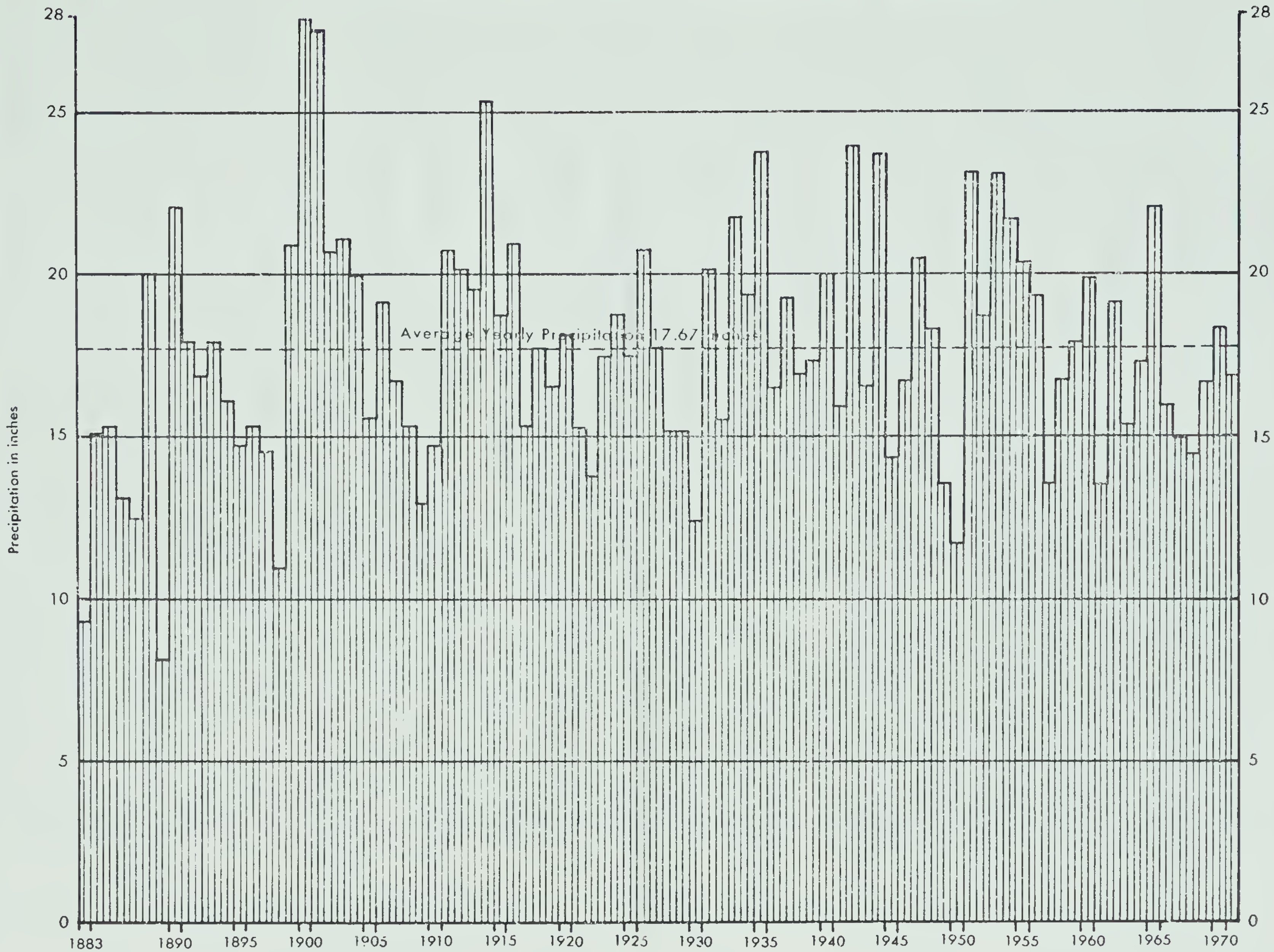


Figure 9

ANNUAL PRECIPITATION TOTALS FOR WHITEMUD CREEK BASIN



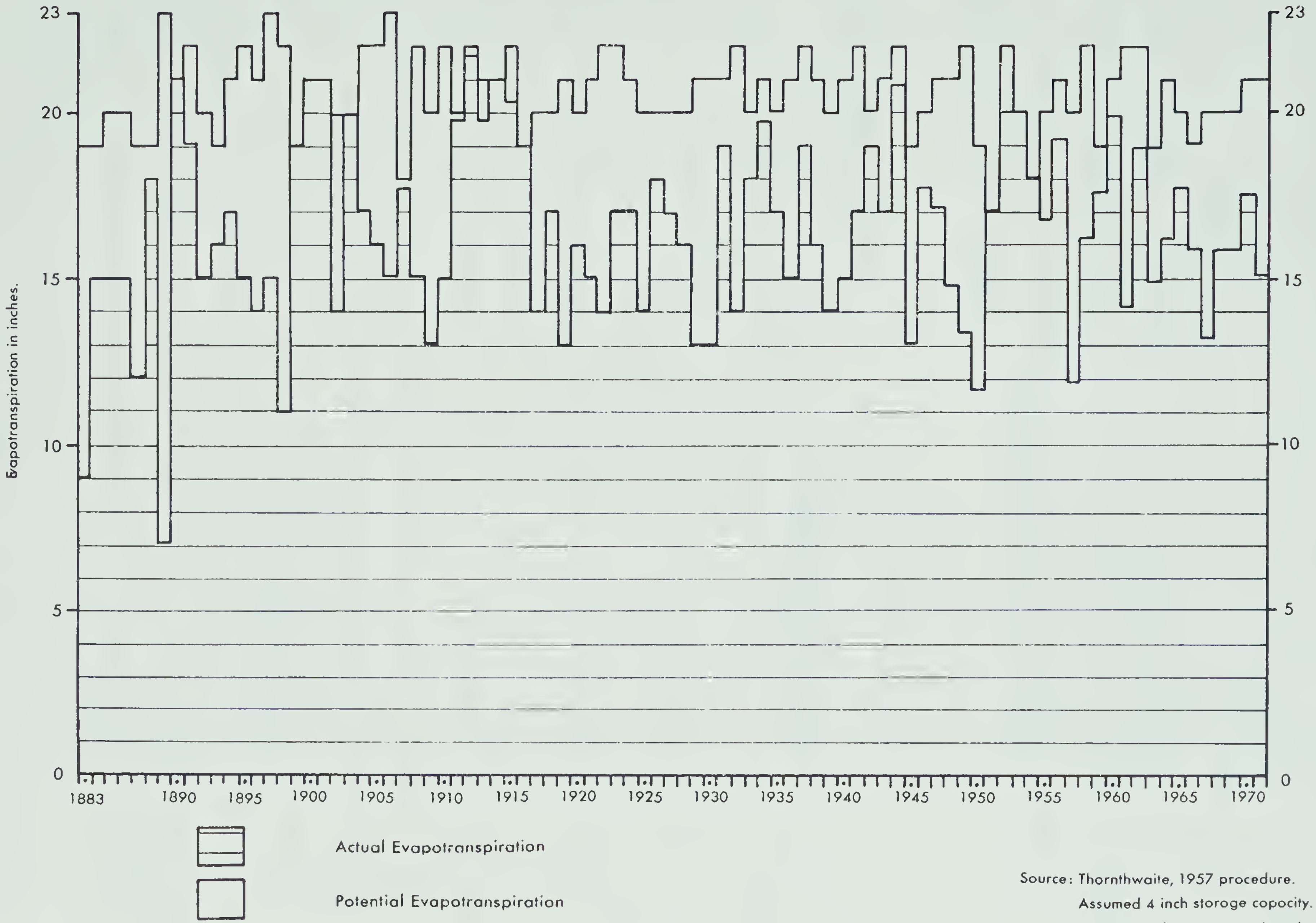
Source: Annual Meteorological Summary, Edmonton:
Met. Div. Cdn. Dept. of Transport.
Averages of stations mentioned in thesis.

the growing season. Due to the foregoing property of rain falling in the summer months, no runoff results from vegetated lands except during extended periods of rainfall. Bowser, et. al., (1962) concluded that only one year in five is liable, on the average, to produce rainfall of over one inch in an hour. Thus the potential for runoff to take place during the period of maximum rainfall is not extreme, provided surface sealing of soils does not occur. Verma and Toogood (1968) indicated that on comparing rainfall and intensity with infiltration rates, virtually all the soils in the Edmonton area, except paved surfaces, will readily absorb rain falling at a maximum of one hour intensities that are likely to occur in the area.

Analyses of data by Laycock (1967), for a 30-year period 1921 - 1950, showed that the local area has a moisture deficit for the growing season varying from 2.0 to 8.5 inches (under the assumption of a 4 inch available storage capacity). For the study area, the annual deficit for the 89-year period varies from 0 to 15.55 inches. Some of the data from the earlier years are questionable but could be correct. The pattern of annual deficit is indicated on Figure 10 as the difference between potential and actual evapotranspiration. From this Figure it is evident that the potential evapotranspiration (PE) does not vary as much, over the 89-year record, as the actual evapotranspiration (AE). That is, over a short period, changes in both PE and AE are more discernible. The Figure also shows general differences in PE and AE before and after the 1920's. Up to about the 1920's cyclical pattern tendencies of approximately ten years of PE and AE relationships show up. After the 1920's there is much more variability in the pattern of PE and AE.

Figure 10

ANNUAL ACTUAL AND POTENTIAL EVAPOTRANSPIRATION FOR WHITEMUD CREEK BASIN



Source: Thornthwaite, 1957 procedure.
Assumed 4 inch storage capacity.
Averages of stations mentioned in thesis, also Appendix A.

There is marked variability in both temperature and precipitation for given seasons and from one year to the next. The accompanying Figures illustrate the variability of the patterns over a year and also over the 89-year record. Reference to these Figures and represented patterns have been discussed. Depending on these foregoing conditions, in combination with other ones, the surface runoff and the creek's discharge may be accentuated considerably in some years and in others, relatively insignificant flows result.

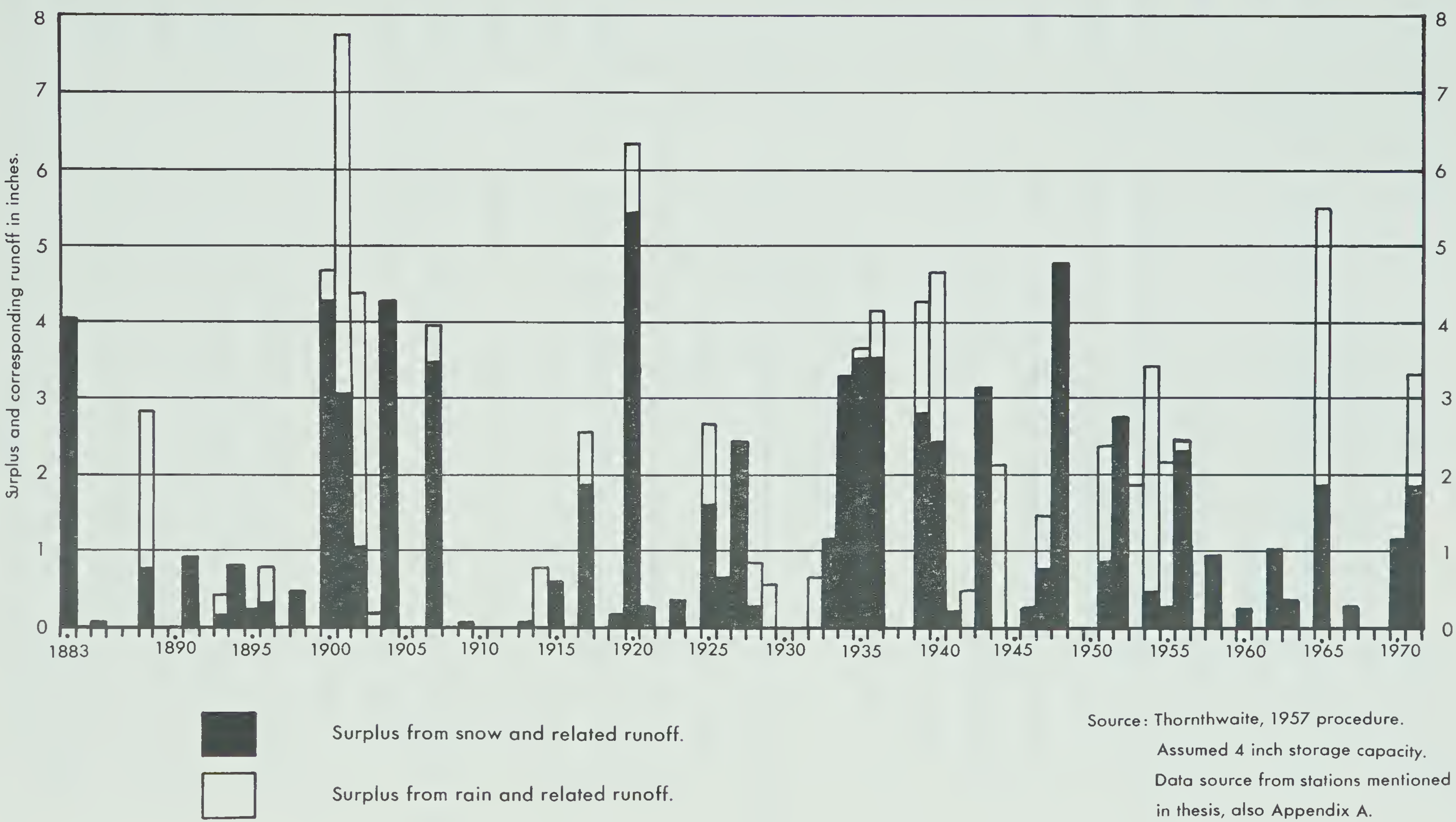
HYDROLOGIC CHARACTERISTICS

The climate data of the local temperature and precipitation were processed according to the Thornthwaite and Mather (1955) bookkeeping procedure. For the analyses the writer assumed a four inch storage capacity, employed the 1957 tables, further assumed no descending rate of soil moisture utilization as the wilting point is approached, and other relationships required for evaluating the water balance. From the results of the computations (see Appendix A) suggestions were made as to the general patterns of water surplus and surface runoff. The surpluses are highly variable from one year to the next. The average amount of surplus in the study area for the 89-year period amounts to 1.29 inches, but surplus has varied from 0 in 32 years of record to a maximum of 7.77 inches in 1901 during this time span. Some years have less than one inch of surplus or no surplus and subsequent runoff. Such years rarely occur in long succession (see Appendix A).

The pattern of surplus amounts resulting from the types of precipitation are graphically presented in Figure 11. On further examination of the long-term climatic records presented in Appendix A,

Figure 11

SURPLUS OF PRECIPITATION AND CORRESPONDING INCHES OF RUNOFF IN WHITEMUD CREEK BASIN



Source: Thornthwaite, 1957 procedure.
Assumed 4 inch storage capacity.
Data source from stations mentioned in thesis, also Appendix A.

it can be shown that in 32 out of the 89 years there was less than one inch or no surplus and runoff. The remaining 57 years can be broken into 27 years of snow surplus and corresponding runoff (47.37 per cent of the time), 9 years of rainfall surplus and runoff (15.79 per cent of the time), and 21 years (36.84 per cent of the time) in which surplus and subsequent runoff resulted from a combination of both snow and rain. That is, snowmelt and summer rains in those years were significant to yield surpluses. The above calculations were based on the assumption that when the mean monthly temperature was below 32 degrees Fahrenheit (including April), all the precipitation that fell during that month was considered to be snow. Any precipitation that fell when the temperature was higher was considered to be rain.

The preceding data were computed from the years where surpluses resulted. The surplus values were separated into three types, those resulting from snow, from rain and from both. The years having surplus values corresponding to one of the three types were then added together. The percentages of years were then calculated from the 57 years in which surpluses took place. Whenever and from what type of precipitation surplus occurs, an important property, which influences the volumes of subsequent runoff, is the amount of water in soil moisture storage. The rain and snow surpluses in any month or year are not usually independent of each other. Although most of the precipitation occurs during the summer, it is the accumulating snow in winter which makes surpluses possible and contributes to a more significant runoff pattern.

There are important seasonal and local exceptions to the surface runoff patterns. Local surpluses are usually derived from both snowmelt and spring rains. Prolonged periods of rain in summer may

produce a significant surface runoff. This latter condition is in fact illustrated in Figure 12. Considerable rain during the end of June and the beginning of July in 1970 (9.04 inches) and again in 1971 (8.80 inches) produced significant surface runoff and measurable streamflow especially from paved areas and agricultural lands in the basin. Laycock (1959) believed that some of the runoff never reaches major streams, but that it merely collects in depressions and is lost mainly by evaporation. The Whitemud Creek Basin though, has less depression storage than most other basins and ditching has added to outflow.

One of the main parameters in the Thornthwaite procedure is potential evapotranspiration (PE). It was calculated from temperature data and daylength. The actual evapotranspiration (AE) is equal to water that is actually consumed through evaporation and transpiration (that is PE-D). However, when the precipitation is less than the demands for water, and moisture in storage is no longer available, the AE is less than the PE. The amount by which the AE falls short of the PE, is the moisture deficit.

A comparison of precipitation with the actual evapotranspiration indicates whether the soil moisture storage is depleted or augmented, and by how much. Once the soil has been recharged to field capacity, any further addition of water results in groundwater recharge and/or in surface runoff. In addition, if rainfall or snowmelt have exceeded infiltration capacities, whether the soils have been recharged to average designated amounts or not, a surplus in surface runoff may also take place. The amount of runoff that results from the excess precipitation is governed by such factors as temperature, moisture deficit, and

the current potential evapotranspiration.

Streamflow and Hydrograph Analyses of Whitemud Creek

The climate, described previously, produces a particular pattern of runoff and streamflow in the Whitemud Creek Basin. The runoff patterns from various land use areas in the basin are examined in chapter four. In this section the writer describes some of the streamflow characteristics of the main creek.

Kakela (1969) noted that streamflow is an important variable of the water balance. He outlined three important characteristics:

1) Streamflow is an areal measurement of water (that is, the total surplus water running out of a drainage basin), rather than a point observation such as temperature or precipitation.
2) Streamflow is a dependent variable in the water balance, it is a residual quantity of the initial water supply (precipitation) after evaporation and transpiration have taken their share and storage change has resulted.
3) Streamflow from a large basin is concentrated into a relatively small channel, and the flow volumes that result are comparatively large but can be measured with reasonable accuracy at an automated recording gauge site.

There is a paucity of data on specific discharges in small basins for the region. Streamflow data for the study area were obtained from the Water Survey of Canada which has been operating an automatic gauge on Whitemud Creek since the spring of 1969. Additional information was obtained from the Alberta Water Resources Division which has been taking flood-peak discharge measurements on the creek since 1960. These measurements indicate the following variations in peak discharges over that time period. The values of Table 1 were obtained from the Alberta Water Resources Branch which has observed these high flows at a bridge where the Nisku Road crosses the creek.

TABLE 1

PEAK DISCHARGES OF WHITEMUD CREEK

Year	Volume (cfs)	Year	Volume (cfs)
1960	600	1967	630
1961	465	1968	1,075
1962	1,250	1969	950
1963	225	1970	925
1964	390	1971	1,650
1965	640	1972	583
1966	1,100		

Source: Unpublished data, Alberta Water Resources Division, Edmonton.

In addition to these records, total discharges for the basin are shown in Table 2 and also in Appendix B, C, D and E. These unpublished and preliminary data were obtained from the Water Survey of Canada. Both 1969 and 1972 data are incomplete.

Appendix B is a listing of mean daily discharge in cubic feet per second (cfs) recorded during May, June, August and September of 1969. No flow was recorded during July. Three separate flow periods are evident, May 13 to June 3, August 6 to 13, and September 5 to 12. The yield of 0.006 inch (Table 2) for the basin in that year was negligible in comparison to the following years. This was due to the delayed start of the automatic gauge which was installed late, and thus missed much of the early snowmelt runoff volume.

In Appendix C, mean daily discharges in cfs are recorded for the period April 3 to August 23 inclusive (143 days) for 1970. The creek had a continuous flow during this period. Two peaks in flow were recorded. The first took place early in April when snowmelt was greatest, but then discharge declined gradually. A second increase in flow occurred early in July due to summer rains, but by the end of August flow had stopped. The basin's yield for 1970 amounted to 1.62 inches (Table 2).

The mean daily discharge in cfs for 1971 from April 9 through to August 24 is shown in Appendix D. As in 1970 there was a continuous flow over this 138 day period. Two peaks in discharge were again recorded. The second increase in flow took place early in July due to summer rains, as in 1970. After that, flow decreased slowly and ceased on August 24. In 1971 the yield of the basin was 2.52 inches (Table 2).

Appendix E is a listing of mean daily discharge in cfs for 1972 from March 21 to April 24 inclusive. This is only a partial record available up to this time. A high discharge occurred on April 7, but then flow decreased gradually. Up to April 24 the basin's yield amounted to 1.49 inches (Table 2).

These tables illustrate the variations in flow of the creek. Although the observed records encompass a relatively short period, significant and characteristic properties of the creek's flow can be illustrated from them. The volume of streamflow is small and variable. Nearly all of the streamflow is obtained from surface runoff, with both melting snow and summer rains contributing. This will become more evident later in the discussions on the creek's hydrographs for the years 1969 - 1972.

TABLE 2

TOTAL DISCHARGE OF WHITEMUD CREEK BASIN

Year	Volume		
	Acre Feet	Total yield in inches	Yield for basin in inches
1969	44.03*	528.21*	0.006*
1970	12,300.00	147,659.06	1.62
1971	19,100.00	229,291.71	2.52
1972	11,300.00*	135,654.26*	1.49*

Note: * incomplete data
Source: Unpublished, preliminary data. Water Survey of Canada, Calgary.

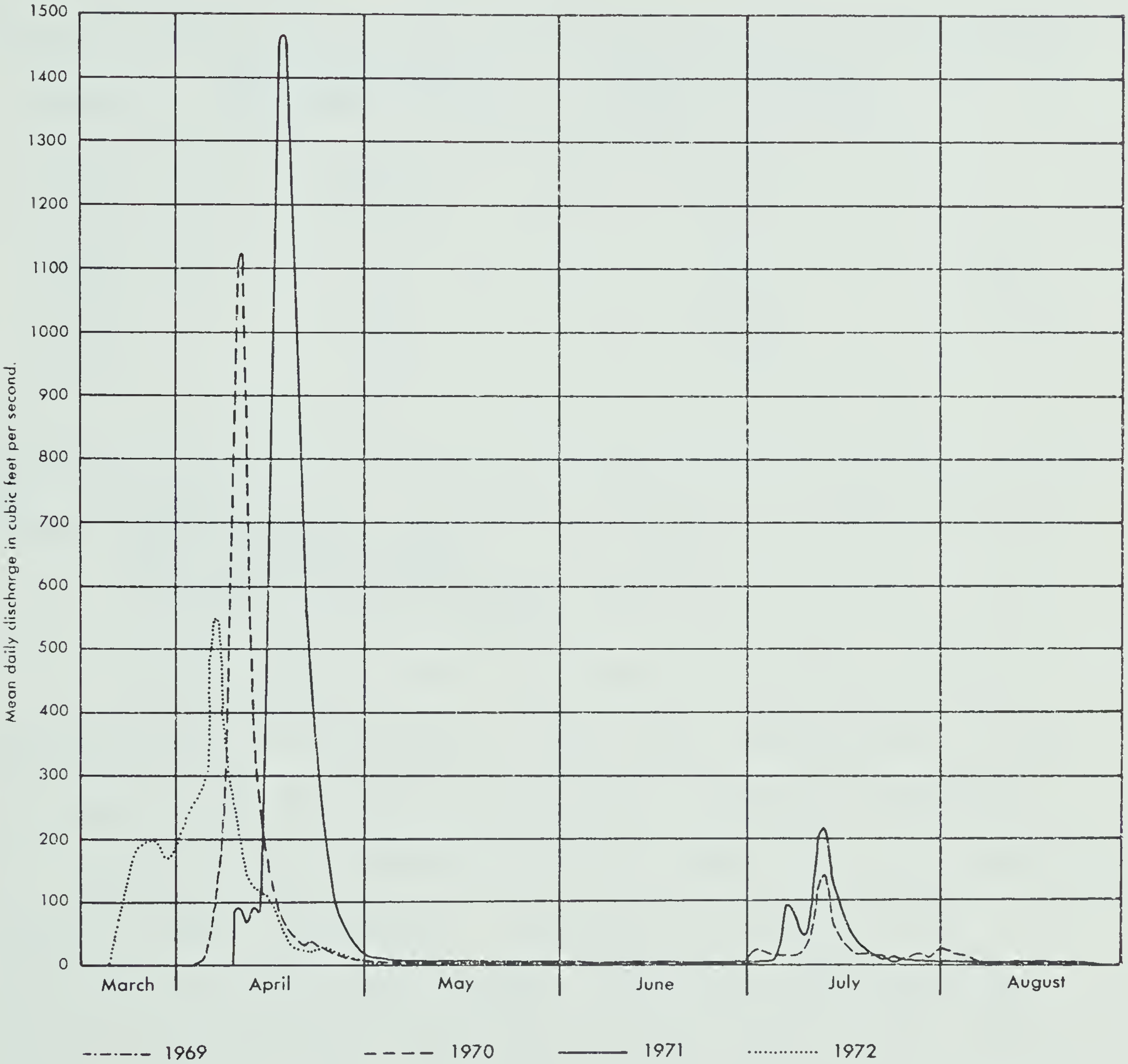
The surplus values derived from the Thornthwaite procedure (Appendix A) were calculated as previously discussed. Discharge values were computed from them to indicate long-term trends. Table 3 is a summary of the results of measured runoff with runoff estimated from climatic data for the last four years. The last column indicates how close the estimated values are to the measured ones.

To illustrate the climatic effect upon Whitemud Creek, the hydrographs for the four years of record, up to the end of April 1972, are shown in Figure 12. These curves depict the typical variable seasonal discharge patterns.

The creek's 1969 flow is hardly evident on the Figure. This was the first year for the automatic gauge on the creek, and by the time it was fully installed and operational, most of the limited discharge

Figure 12

HYDROGRAPHS OF WHITEMUD CREEK 1969-1972



Source: Canada Water Survey Branch.
Preliminary unpublished data.

had probably already passed by. The flow of the following three years is very evident and each shall be dealt with.

TABLE 3

MEASURED AND OBSERVED RUNOFF OF WHITEMUD CREEK BASIN

Year	Measured runoff of the basin in inches	Estimated runoff of the basin in inches	Per Cent
1969	0.006*	0	-
1970	1.62	1.17	72.22
1971	2.52	1.86	73.89
1972	1.49*	1.71*	-

Note: *incomplete data.
Sources: Measured runoff values from preliminary unpublished data from Water Survey of Canada.
Estimated runoff values from Thornthwaite procedure, assuming a four inch storage capacity.

In 1970 the first flow was recorded on the third of April. Before discussing the hydrograph for this year, mention should be made that approximately 2.90 inches of water were retained and detained as soil moisture storage and snow at the end of 1969 (a four inch capacity is assumed in these calculations). The amount in storage partially influenced the ensuing surface runoff. The average temperatures for January, through to March of 1970 were all well below freezing. The snow that fell during those months went into storage. It was only during the month of April, and also the latter part of March when temperatures rose above freezing. At this time the soils were being recharged and potential evapotranspiration was very low or even absent.

Thus most of the excess waters likely contributed towards runoff. With increasingly warm temperatures during April, the discharge jumped quickly to a maximum of 1,120 cubic feet per second (cfs) on April 11. This is shown graphically on Figure 12 by the rising limb of that year's hydrograph. Any diurnal variations in flow, which may have been noticed on a smaller scale were masked by basin lag including channel storage upstream and the larger flow at the gauging site. From April 11 onwards to approximately May 3, the flow steadily declined. This trend can be attributed to increasingly warmer temperatures and wind that added to evaporation and transpiration losses, increased soil moisture storage recharge and other processes that were using the excess waters. A very low flow took place from May 4 to the end of June. The low flow at this time tends to indicate that the contributions from groundwater, interflow and depression storage are extremely small. During May, June and July, 1.55, 3.67, and 5.37 inches of rain respectively, fell on the basin. These accumulating amounts were sufficient to bring soil moisture storage in some areas to field capacity. Consequently runoff occurred, and in sufficient quantities (maximum of 144 cfs) to be recorded. The lack of a higher and more sustained flow indicates the preponderence of potential evapotranspiration over precipitation for most of the period and the need for soil moisture recharge before runoff could take place. After these summer rains the hydrograph once again declined to very low values (see Figure 12 and Appendix C), and eventually to zero on August 23. The low values at the end of the hydrograph clearly show that groundwater contributions are negligible. This recurrent feature is also evident on the hydrograph from 1971. At the end of 1970 approximately 2.54 inches of moisture were retained as storage in the soil.

It can be noted from Figure 12, that very similar patterns in runoff occurred in 1970 and 1971. Once again, during the first three months of 1971 cold temperatures persisted and the snow that fell remained on the surface as surface detention storage without significant loss to evaporation or runoff. Runoff began to be observed at the gauging site on April 9. Similar conditions of soil moisture recharge and low potential evapotranspiration, combined with rapidly increasing warmer temperatures, as in 1970, created a flashy spring runoff. Other factors which contributed to this flashier and larger flow are a greater soil moisture storage in the fall before freeze-up,a greater snowfall with hardly any melting during the winter, and higher temperatures in the later snowmelt period. From a low value of 8 cfs on April 9, the discharge increased to a maximum of 1,450 cfs seven days later on April 16. Plate 3 indicates the flow conditions at the gauging site on April 17, 1971. Slightly cooler temperatures for two days, preceding the peak flow, caused a small dip in discharge and this is shown on the 1971 curve on Figure 12. After that slight decrease, the flow steadily increased to the maximum. From April 17 onwards to May 10, the flow decreased until it again approached the low flow conditions as in 1970. In the months of May, June, and July, 0.53, 3.42, and 5.38 inches of rain respectively, again fell on the basin. This amounted to 1.26 inches of rain less than in 1970, and yet more runoff occurred in 1971 over the same period. Several factors that contributed to this difference are a greater soil moisture storage recharge resulting from a greater snowfall and the slightly cooler temperatures of 1971 which resulted in a smaller potential evapotranspiration than in 1970. This consequently was reflected in the trend of the hydrograph at this time.

PLATE 3

Plate showing the rapid, flashy, high flow during the spring snowmelt runoff period 1971. The plate shows the conditions at the automatic gauge on April 17, 1971 just after the crest passed by. At the time that the photo was taken, discharge past the gauge was 1,450 cubic feet per second. The hydrograph for 1971 on Figure 12 graphically illustrates the flow condition at that time.

The curve for 1971 on Figure 12 shows two peaks in July from summer rains. The first increase in flow on July 7 was primarily due to the quick, flashy runoff from the International Airport pavement areas. The flow then decreased from 96.8 cfs to 44.4 cfs on July 10. This trend was attributed to decreasing daily rainfall and also to the surplus from other parts in the upstream areas of the basin, which had not yet reached the gauging station. Once the surplus, due to basin lag conditions, reached the gauge, the flow rose quickly again to a peak of 227 cfs on July 13. The cooler average temperatures of May, June and July in 1971 also contributed to lower potential evapotranspiration and much more moisture being retained as storage in the soil, detained in depressions and channel storage and used sparingly. Thus, when rainfall occurred during these months, less moisture was required to attain field capacity. Runoff consequently was slightly higher during the summer months in 1971 than in 1970. This pattern is also well illustrated on Figure 12. From a peak flow of 227 cfs on July 13, the flow steadily decreased until it ceased on August 24. Plate 4 shows the flow conditions on July 13, 1971. No flow was recorded during the remainder of the year. The long dry period from mid July until late August had some flow from channel and bank storage, but the relative lack of groundwater contributions is indicated by the absence of flow in late summer. At the end of 1971, approximately 2.12 inches of moisture were retained in the soil. Plate 5 shows the gauging site at time of freeze-up in October 1971 when no flow took place.

During January and February of 1972 much cooler temperatures persisted in the area than in either 1970 or 1971. In March, mild temperatures caused much earlier runoff than in the three preceding years.

PLATE 4

This plate shows the rapid flow during the summer that results from extended periods of rainfall. The photo was taken at the automatic gauge at time of high flow (July 13, 1971) when the discharge was 227 cubic feet per second. The condition of flow is also shown on Figure 12.

The more turbulent flow slightly upstream from the gauge is due to water flowing over a beaver dam that is obstructing flow.

PLATE 5

Plate showing the conditions in the creek at the gauging station on October 17, 1971. Photo taken at the time of freeze-up when no flow was noted past the gauge. Note the beaver dam upstream from the gauge.

The first discharge was recorded at the automatic gauge on March 21. Runoff on a smaller scale actually started several days earlier under the influence of mild temperatures. From March 21 to the end of the month, streamflow increased gradually to a maximum of 200 cfs. With a return of cold temperatures, discharge decreased slightly. From April 2 to April 7 warmer temperaturs returned and streamflow increased to a maximum of 547 cfs in that year. After this date, fluctuating warm and cold temperatures persisted, with the occasional snow shower. Approximately 6.3 inches of wet slushy snow fell on the basin on April 21, but it took close to three days for this precipitation to be recorded as discharge at the gauge. After that date, the hydrograph curve steadily declined to a low level as in 1970, and 1971.

Much lower discharge occurred in 1972 than in either 1970 or 1971. This resulted from a lesser soil moisture supply in storage, a moderately heavy winter snowfall (67 inches), and more evaporation and infiltration during a more extended snowmelt runoff period.

Thus generally, there are no flows recorded during the months from September through to the middle of March. From approximately the end of March to the middle of April, the discharge rapidly peaks. This trend is attributed to an increase in temperature causing rapid melting of snow and creating quick, flashy runoff. Additional amounts of water from spring rains also contribute to this high flow during the spring months. Evaporation is also relatively low at this time. From the end of April through May and to the end of August very low or practically no discharge occurs. The only flow that is recorded is due to extended periods of heavy rainfall. At this time of the year both evaporation and transpiration are high and much moisture is consumed. Later in the

autumn streamflow ceases until the following spring.

The pronounced peaks followed by virtually no flow, in a year, indicate how very small the groundwater contribution is in the basin. Minor seepages from interflow likely drain into the channels from higher areas and contribute a very small amount to the whole flow. The low flow of both snowmelt and rainfall are relatively similar, except that the low flow from snowmelt persists slightly longer than that from short duration rainfall. It is hard to determine just how long each type persists. On the foregoing analyses, it can be concluded that Whitemud Creek has a variable seasonal flow pattern that is determined to a large extent by the climatic conditions in the area.

SUMMARY

In this chapter the writer has discussed several different factors that tend to influence runoff in the basin. Such factors as geology, topography, soil types, climate, land use and vegetation were examined. Climate is the main determining factor. In addition to this one, other determinants of runoff are slopes, the steeper the slope, the quicker the rate of runoff; the vegetation and ground cover, which create differences in evaporation losses, infiltration and storage capacities and in snow accumulation patterns, and thereby runoff; aspect, which creates differences the timing and rate of snowmelt; area, the larger the size of a basin, the greater the runoff and also the greater the basin lag, channel storage and other elements; drainage density, the more channels a basin has, the better is its efficiency for draining the land, thus flashier flow and high runoff results; channel alignment, the straighter the channels, the quicker the runoff passes through them.

These and many other differences in physical characteristics cause differences in runoff patterns.

A more detailed list of factors affecting runoff was presented by Chow (1964) in Section 14-2 of the "Handbook of Applied Hydrology". He split the factors into climatic and physiographic ones, and in each of these categories he listed several sub-factors. Any one or a combination of the factors may be of particular significance not only in the Whitemud Creek Basin, but also in any other drainage basin. It is not the writer's purpose to deal with all of the physical characteristics and factors, but to indicate some which have a significant effect on runoff in the basin.

Ward (1967) also dealt with factors affecting runoff. In addition to the climatic and physiographic factors mentioned by Chow (1964), he discussed human factors. He proposed that the pattern and distribution of runoff has been changed due to the influence of man. Such changes as the removal of forests, the cultivation of grasslands, the drainage of marshes, and the increasing spread of ditches and artificial impermeable surfaces have taken place in the Whitemud Creek Basin. Their effect on runoff will be discussed in chapters 3 and 4.

The resultant hydrograph of discharge from the basin is a unique expression of many interactions, for example of soil, geology, water and vegetation, which are rarely replicated in a similar combination in any other basin. Lassen, et. al., (1952) noted that, by providing a common product - streamflow - the net effects of these interactions on that product can be measured and appraised.

CHAPTER III

THE EFFECT OF CHANGING LAND USES IN THE BASIN

In the previous chapter the focus of discussion was the physical characteristics of the Whitemud Creek Basin. This chapter describes some of the changes in land use that have taken place in the watershed. Several of the possible effects of these alterations on runoff patterns will be discussed. The sites selected for more detailed examination of runoff patterns for this study will also be described.

HISTORICAL DEVELOPMENT

As indicated in chapter two, there is a paucity of streamflow discharge data. This is also partially true for specific information on vegetation and land use changes for the Whitemud Creek Basin. The writer here relies on several sources of material including the homesteading files held by the Alberta Department of Lands and Forests, the reports of land surveyors kept by the Alberta Department of Highways, the records held in the Provincial Archives and other sources to derive or interpret the pattern of vegetation and land use change through time. This library research was an essential part of this study assisting in the description of the conditions of the land, especially for the period before the coming of the settlers. The characteristics of vegetative cover and watershed use at any time are significant and necessary for

the interpretation of relationships that may exist between these and the runoff patterns or streamflow characteristics of the watershed.

Pre-settlement Conditions

The study area is located in the parkland prairie region which consists of patches of forest and wooded areas amongst open grassland prairie. Moss (1955) described the parkland as a transitional zone containing both open grassland and poplar forest. The dominant tree species in areas of the parkland prairie is the aspen poplar, and it also predominates in the study area. Spruce trees occur frequently as well throughout the area.

It is somewhat difficult to ascertain what type of conditions prevailed before the influx of settlers onto the land. A certain percentage of land in the basin is in agricultural, urban and other use, and the "natural" vegetation which remains may well have been altered by man or other agents. Buffalo and elk extensively grazed the grassland, browsed the shrubs, and destroyed trees by rubbing and trampling. Such processes retarded the succession of the lands to forest. Additional areas under woodland were reduced by fires set by the Indians. Once settlement took place, fires were reduced, the wild animals decreased in numbers and the forest encroached on the grassland. Thus considerable changes in the relative distribution of grasses and trees may have taken place in time. Savage (1965, p. 517) indicated that there has been a marked tendency for poplar to encroach upon grassland area.

In chapter two reference was made that parcels of vegetation in the basin can be considered as indicators or representative of the "natural" vegetation. A more reasonably accurate picture of vegetation before the influx of settlers, however, can be pieced together from

historical records including maps, photos, paintings and other sources left by observers more or less contemporary with the time.

The first "survey" of the area was made in 1858 and 1859 by Captain Palliser and his party of scientists. He noted that the district was rich in prairie land and had scanty woods mixed in. P. Kane (1850), the famed artist of the Canadian west, recorded various representative scenes of the local area on canvas.

It is also noteworthy to indicate that as the vegetation patterns changed, due to variable climatic patterns, so did the kinds of soil. A semi-arid climate contributed to the development of the soil characteristic of the grassland prairie. Precipitation during those times was low and evapotranspiration was high. Under more humid conditions such as have likely prevailed for several centuries of the latter part of the Quaternary Period, darker soils of the parkland prairie developed. Due to the fluctuating postglacial climatic conditions distinct patterns in both soil and vegetation were left on the landscape, (Webb, Johnston and Soper; Alberta, A Natural History, p. 96). They also stated that most of the period since glaciation (4,000 to 8,000 years ago) was considerably warmer and drier than the more recent past. These conditions help to explain why there is a general lack of well-developed surface drainage channels throughout the area. That is, the more cooler and moist climate is only a more recent agent of soil degradation and drainageway formation.

For the most part, the vegetation pattern that was evident at the time of the original land survey in 1887 may well have been altered by man or other agents. The land in its "natural" conditions was observed by the Dominion Land Surveyors who surveyed the townships

through which the creek and its tributaries pass. Several of the descriptions of the surveyors who made the observations and recorded them are presented. The descriptions that follow are given in a north to south direction, that is, from the creek's mouth to its headwaters.

W.Beatty (1883) described the township at the creek's mouth as one covered with poplar and willow and having some tamarac and spruce of fair size. L. R. Ard (1883) described the lands further south as open prairieland with poplar and willow bush, interspersed with patches of spruce. D. Beatty (1883) recorded that the lands south of the last township were timbered throughout with poplar, except where there are some willow patches of scrub and dry muskeg. W. Beatty (1883) described another township through which the creek passes. The western half was low and swampy and covered with dense poplar and willow and also patches of spruce. The east half was more open prairie grassland and somewhat higher and was covered with poplar and willow. The lands of the central part of the basin had poplar bluffs, spruce and tall willows and patches of grassland (D. Beatty, L. R. Ard, C. A. Magrath, 1883). G. McPhilips (1893) followed up the previous description. He stated that much of the land was covered with water from the effects of obstructions in the streams and the existence of a great number of beaver dams, that little of this area was at that time fit for settlement. He mentioned that it was possible to drain the lands. In addition there were no openings in the forests on the drier parts of the land and settlement would be slow. He suggested that fires would clear away much useless willow and scrub and give the land a chance to dry. The township east of the previous one, surveyed by W. Beatty (1883), was also covered with poplar, willows and patches of spruce and small openings of scrub prairie.

J. J. McArthur (1884) described the western portions of the creek's headwaters as prairie covered with scattered poplar and willow. W. Beatty (1884) recorded that the rest of the headwater region was low and wet and well-watered by running brooks and small ponds. The vegetation was small poplar, willow, some spruce and an occasional marsh. Much later, in 1918 H. M. R. Soars surveyed the water areas of the region and reported on the conditions and the effects on properties, insofar the extent of flooding and possible land use are concerned. In one instance he surveyed a lake affecting a large portion in the southeast corner of the basin's headwater area. This site was selected as one of the representative plots in this study. Soars reported this to be a shallow surface-fed slough containing two feet of open water. His field notes show that a drainage ditch had been constructed leading out of the northern end of the slough. This ditch still exists at the present time. It is in this ditch where one of the weirs for measuring the amount of runoff from the area contributing meltwater to the slough was erected.

What then can one extract from the foregoing information? These observations help in determining and reconstructing the characteristics of the land before intensive settlement. They also assist in establishing the conditions and patterns, not only of runoff, but also of the flow regime of Whitemud Creek. The fact that no discharge records were taken during these times prompted the use of the Thornthwaite water budgeting procedure in deriving surplus and runoff values for those years for which no actual measurements were performed. This procedure makes it possible to establish some assumptions that are supported with some certainty and factual evidence.

The Thornthwaite procedure was used for indicating different

storage relationships to land use. Calculations using three average storage capacities - 2, 4 and 6 inches - when used with the long-term climatic data, resulted in average annual surpluses of 2.89, 1.29 and 0.72 inches respectively. These values are indicative of the amounts of runoff that can be expected in areas under different land uses. For example, soils in a wooded area having a storage capacity of six inches, would be able to absorb much moisture and only a small amount would remain for runoff. A cultivated cropland area having a lesser storage capacity than a forested area would yield higher runoff. A relatively impermeable surface such as pavements having an extremely low storage capacity would have the highest amounts of runoff. Thus it is probable that runoff would have changed with changes in use from forest to cultivated cropland areas and to more intensive urban use.

At the time that more trees were present on the basin, the snow was distributed much more evenly and the effect of snow redistribution by wind was negligible. The shading effect of the vegetation caused the snow to remain longer in these areas. There was also better detention storage in the past with more trees. Thus the wooded areas, having a low albedo had a high potential evapotranspiration, created a lag in snowmelt and most of the water that ran off was consumed locally by the forest cover.

Once the bush areas were removed by settlers, grass production increased and this contributed towards altering the hydrologic regime of the basin. More on the effects of such alterations as albedo patterns, cultivation techniques, ditching, drifting and others will be discussed in the section "Effects of Settlement". The end result of the conditions, existing under a more forested basin before large clearing took place,

would be less water available for surface runoff.

Thornthwaite (1946) noted that minor differences of potential evapotranspiration (PE) among vegetation types are a consequence of slightly different albedo patterns, hence in absorption of insolation. On the basis of changing albedo as a result of unrestricted human activity in the landscape, PE gradually decreased wherever open agricultural land evolved from woodland. The following studies support the fact that changes in PE and albedo are related to changes in land use. Thornthwaite (1954, p. 205) stated that potential evapotranspiration differs for different types of vegetation because of differences in albedo. He further adds, the greater the albedo, the more of the incoming solar radiation that is reflected back to the sky and the less that remains for heating and for evaporation. In a later study, Thornthwaite (1955, p. 17) noted that evapotranspiration depends on:

1) The external supply of energy to the evaporating surface, principally by solar radiation.
2) The capacity of air to remove vapour, that is, wind speed, turbulent structure and decrease of vapour concentration with height.
3) The nature of the vegetation, especially as regards its capacity to reflect incident radiation, the extent to which it fully occupies the soil, and the root system.
4) The nature of the soil, especially the amount of available water in the root zone.

Conditions such as those previously described and others all contributed to significant alterations in the basin's quantity, quality and timing of runoff.

Hibbert (1969) conducted an experiment in which a 22-acre watershed in the southern Appalachians was changed from forest to grass cover. He found that in years of low grass productivity the water yield was higher than from the forest. Hibbert (1967) indicated that, in well-watered regions of the eastern United States, streamflow response

was proportional to the reduction in forest cover. The streamflow response though, varies with the amount of precipitation, season of the year, rates of evapotranspiration and other factors. Such factors control the soil water content and ultimately the rate of water release to the stream. If the conclusions of these researchers are valid here, we might assume that, given average conditions similar to those of the past 85 years, (but with variations from year to year as we have had in 1969-1972), in the Whitemud Creek Basin, the streamflow of the creek was slightly lower and more evenly distributed throughout the year. It is now characterized by a flashy flow during the spring melt period and has virtually no flow during the rest of the year, except at times of prolonged rainstorms. A very limited amount of flow may take place from groundwater sources discharging into the lower stream valley.

Hornbeck (1970) presented evidence that sizable water yield increases resulted, from a watershed in central New England converted from forest to grass, especially in the first few years after treatment. Lewis (1968) concluded from experiments conducted on a 12-acre watershed in central California converted to grass, that the average annual increase in water yield was proportional to the annual decrease in consumptive use. Lull and Sopper (1966) found that, for watersheds in the eastern United States, the proportion of forest cover was correlated positively with an equable flow regime. That is, more evenly distributed runoff results from watersheds with a great forest cover. Johnson and Meginnis (1960) presented results from treated plots of the Coweeta watershed in North Carolina, converted back to forest, in which streamflow increasingly declined with time. Schneider and Ayer (1961) also indicated a gradual reduction in total runoff from plots in central New York that were

converted back to forest. Such conclusions derived by the above authors and many others are true for the more humid region watersheds and may not fully apply to this study.

All the foregoing evidence and more, although not directly applicable, tend to indicate trends and support the assumption that, Whitemud Creek Basin as a more forested watershed during pre-settlement times had a higher moisture storage for higher rates of transpiration. Thus the basin had less water available for streamflow. There are still many other factors to be considered such as type and condition of forest, type and amount of precipitation and others. The effect of a forest on runoff is dependent on the interrelationships of these factors (Storey, 1959). Muller (1966) conducted experiments on plots in central New York using energy and water balance models. It is thus also possible to estimate water yield changes for this study using the Thornthwaite procedure. This method is applicable due to the reasonably reliable data on land use changes and vegetation, and climatic trends.

Effects of Settlement

Before the settlers arrived, the Indians in the vicinity practiced burning the grasslands (Bird and Bird, 1967). These two authors further concluded that, throughout the era of early exploration and fur trapping, the grasslands were more open and extensive than they were after settlement began. Thus even before settlement, the aboriginal peoples contributed to changes in the local runoff patterns of the basin. The practice of burning removed brush, grass and much of the ground surface organic material and revealed the bare soil. This may temporarily result in lower albedo of a burnt area and higher potential evapotranspiration. Such conditions tend to lead to more runoff and less soil

moisture storage of an increased water supply. The extra runoff may also be due to concentration of and earlier flow rather than to albedo and potential evapotranspiration changes in summer, following the runoff period.

When the homesteaders arrived between 1890 to 1920, they controlled the brush fires. They tended to settle first the open parcels of prairie grassland in the area, and also cultivated these first because oxen and horses were the main sources of farm power. In addition, the land survey system of the 1880's created townships that consisted of 36 sections of one square mile each. A road allowance 99 feet wide was left around each pair of sections, so that they were one mile apart east to west and two miles apart north to south. Two sections were set aside for school purposes and certain lands were assigned to the Canadian Pacific Railway in the form of land grants. The homestead land was occupied first, and the reserved sections were not sold until later. This type of development created a checkerboard settlement pattern in which much of the land and road allowances were left untouched. It is possible to infer from this type of land use development that the runoff patterns within the basin were probably changed slightly and that the creek's streamflow characteristics likely underwent a similar small alteration. Runoff patterns were possibly changed merely on a local micro-scale wherever developments had taken place.

With the continuing land clearing practices of the settlers woodland areas were reduced. Such removal of wooded areas from some parts in the basin, resulted in the cleared areas having a higher albedo and lower PE than the forest areas. These physical changes altered the snowmelt patterns. With clearing, there would be an earlier and flashier melt of the snowpack and a higher runoff. The open areas that

were created caused alterations in wind patterns and snow and drift accumulation, and subsequent melt patterns. The cultivation techniques practiced by the settlers created seasonal changes in both albedo and PE and these once again affected the runoff patterns. Even at the time of harvest some vegetational cover was removed which consequently had an effect on the final runoff patterns in one way or another. The first introduction of roads and ditches probably contributed to altering the runoff patterns in the basin. Large volumes of snow accumulated in ditches and at the time of spring runoff the ditches conducted the melt-waters quickly and efficiently to natural drainage channels. All the foregoing land use changes and their results contributed to changing runoff patterns on the basin.

The hydrologic regime of the basin had probably progressed gradually from one where slow, evenly distributed flows occurred, to one where much more erratic flow conditions exist due to the changes created by man in the local environment. The greatest alteration in the creek's flow regime was yet to come with the invention of more efficient methods of farming and modern construction practices.

In the 1880's the survey for the Canadian Pacific Railway was begun. Many settlers came into the local district believing that the railway would pass this way, but the survey was changed. In 1891 when the railway line from Calgary to Edmonton, skirting the eastern boundary of the basin, was completed, a land settlement campaign was initiated by the railway. The territory south of Strathcona and adjacent to the railway was a favourite area for settlement and it developed most rapidly. The people who settled this area soon demanded better transportation facilities.

At the beginning of the twentieth century, road expenditures were viewed as urgent. The rapid settlement was not only characteristic of the Whitemud Creek Basin area but of the province on the whole. An active programme was implemented in 1906 to improve, construct and repair roads and bridges. It was in this year too that such a programme was started in the area of the basin. Roads were constructed between sections to places where they were necessary, such as to coal mines. At the same time bridges and culverts were installed where needed for drainage purposes. This active road construction programme further altered the creek's regime. Installation of bridges, culverts, ditches and other artificial drainageways, facilitated quicker and easier removal of surplus waters during snowmelt to natural drainage channels. This network is partially responsible for creating the flashy conditions in the creek's flow.

The transportation facilities that were rapidly increasing and undergoing continuous improvement in the study area prompted the development of mixed farming, which is still the mainstay of most of the farmers. Many farmers have a variety of animals on their establishments including horses, cattle, hogs, sheep and poultry. As well as growing fodder crops for the animals and cereal grains, they also produce some dairy products. In the basin area there are fewer horses now than for example in the early 1900's. There are also fewer farmsteads as a result of farmers selling out and land consolidation taking place. Since the farmers tend to keep more cattle and hogs they also cultivate more lands than previously in order to feed these animals. The raw farm products of the area find a ready market in the city of Edmonton and other centres.

From the early beginnings of agriculture in the basin area,

the acreages of cropland and pasture steadily increased. For example, in the county of Strathcona, which forms a part of the basin, there were 27,612 acres of cropland in 1911. These were mostly parcels of open grassland that required not much clearing and breaking. In 1966 there were 278,333 acres of cropland. Such an increase was also noted in the county of Leduc, which also is a part of the basin, where croplands increased from 26,540 acres to 372,005 acres over the same period. Although a large proportion of the cultivated land was in the basin in each county in 1911, the figures do indicate the intensity with which farming was undertaken in the area. Such large increases, in addition to other land use changes including pastures, improved lands and others, tend to exemplify the alterations which must also have occurred concurrently in the local runoff patterns and streamflow characteristics of Whitemud Creek. Allis and Kelly (1958) noted for watersheds near Hastings, Nebraska, under similar conditions as this basin, that on an annual basis, both the total amount and the peak rate of rainfall were significantly affected by the treatment and use of the watershed area. Dragoun (1969) who conducted his research also near Hastings, Nebraska, illustrated that surface runoff was reduced two years after cultivated fields were converted to perennial grass cover.

Agricultural techniques increasingly underwent refinement and improvement. Tractors, powered first by steam and later by gasoline were such an invention which greatly assisted the settlers in clearing, breaking and working the land. It was not until the introduction of the bulldozer by farmers, around 1945, of more remote parts of Alberta as well as parts of the headwaters of this creek, that many more poplar groves were removed. Many acres were cleared with the help of this machine.

At the same time farmers demanded better roads, and with the local discovery of oil, an improvement programme to roads was undertaken. The implementation of new construction practices resulted in roads with deep ditches and high grades, permitting the snow to be cleared off easier in winter. In the spring and summer the waters from the roads and ditches was drained more easily and quickly to natural drainage channels.

In the late 1950's a significant land use change occurred on an area along the eastern limits of the basin near Leduc. Here, land for the construction of the Edmonton International Airport was expropriated in the fall of 1956. In 1957 the runways were constructed, as well as a hangar. The area has completely different hydrologic characteristics than the vegetated areas. The paved runways and other paved areas have low albedo, that is, they absorb much of the incoming solar radiation. These areas also have extremely low infiltration and moisture storage capacities. The snow melts sooner from the paved areas, and summer rains drain more easily and quickly from them than from vegetated areas. All these characteristics and others contribute to a different local runoff pattern in the basin. This is examined in more detail for two plots described in chapter four.

From the historical evidence presented, it becomes evident that the influx of settlers created great changes in land use and the landscape on the whole. Ditching and road building, improved cultivation practices and soil productivity, drainage of wetlands, improved access and protection, and increasingly improved transportation methods were implemented over the whole basin area. Such alterations of the natural landscape probably produced a slow change in the basin's regime. Conditions

of soil moisture, potential evapotranspiration, soil characteristics, as well as other features underwent some degree of change. Consequently the basin's water yield also underwent changes such as have been noted.

Present State of the Land

Insofar as the existing conditions of the landscape and land use in the basin are concerned, most of the physical description has already been covered in chapters one and two. In this section of the present chapter the fourteen representative plots selected for this study will be described in more detail. The locations of these sub-drainage areas or plots and the instrumentation present from which snowmelt runoff data were collected, are indicated on Figure 13.

A large proportion of the land use in the basin is devoted to the raising of beef and dairy cattle. This category includes many pastures and fields of various types of fodder crops and cereal grains. In addition to these dominant land uses, the other outstanding ones in the basin include scattered patches of shrub and bush, some of which are used as rough pasture for livestock, the network of gravel and all-weather road surfaces, including the paved airport area, a small area of open water consisting of sloughs and ponded water in drainage channels and other uses.

Many agricultural changes have occurred in the basin in the past decade particularly in the greater intensity with which farmers carry out crop cultivation (for better and higher crop yields with the aid of fertilizer, weed control, techniques of ploughing and other improved practices), the more widespread and intensive raising of animals and the improved general management of farmlands. Other noticeable changes that have taken place are the improvement of roads, the location of the Edmonton International Airport on the eastern periphery of the basin and

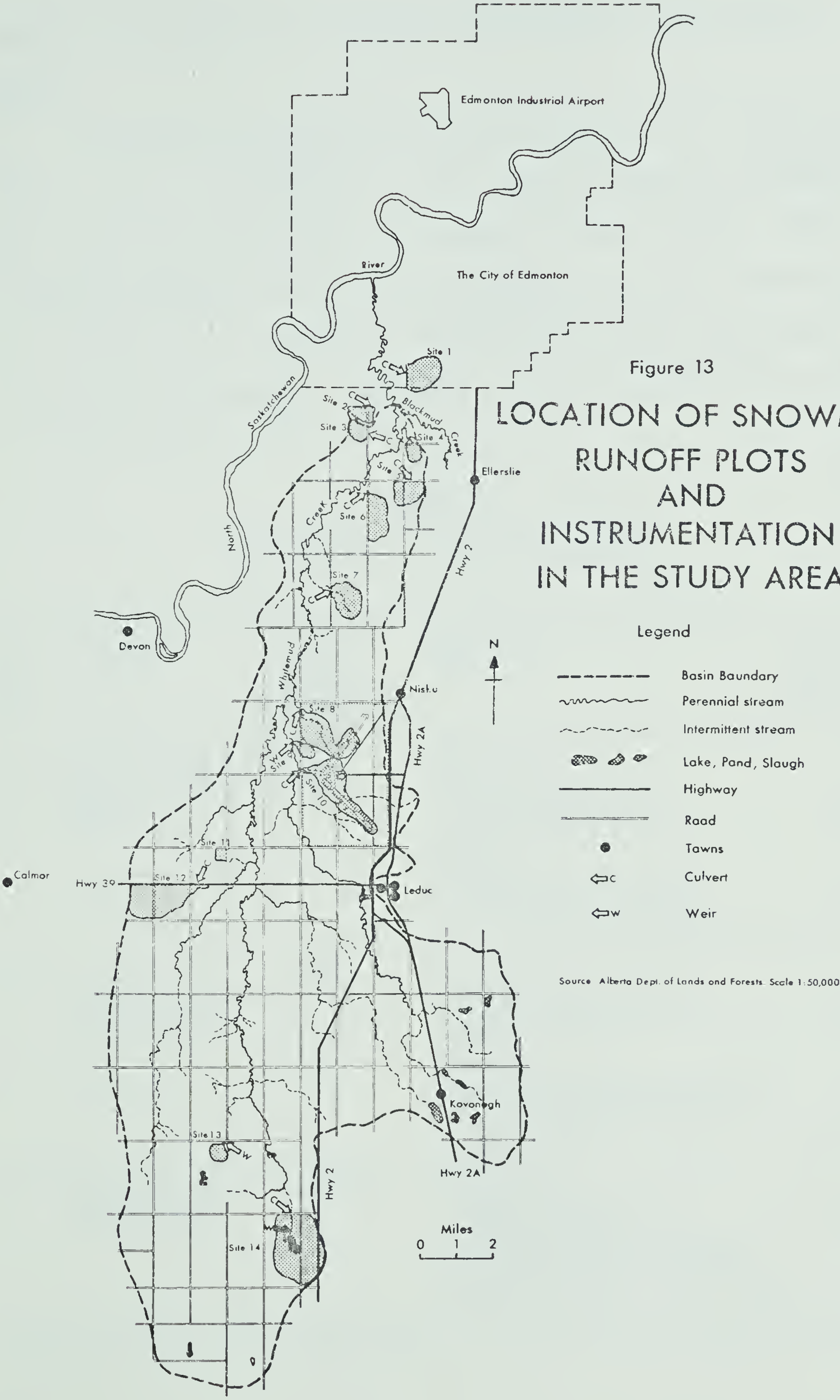


Figure 13

LOCATION OF SNOWMELT RUNOFF PLOTS AND INSTRUMENTATION IN THE STUDY AREA

increase in the number of scattered suburban homes to the south of Edmonton.

The following descriptions of the sites and their characteristic land use types are accompanied by brief summary discussions of their major water balance variations, and expected runoff patterns. The areas of each plot and land use type were calculated with a dot planimeter. This information was supplemented with data from field observations made at the time of the survey. Table 4 is a summary of each site's land use.

TABLE 4

REPRESENTATIVE PLOTS AND LAND USE

Site No.	Location	Total Area In Acres	Land Use	Land Use as Per Cent of Total Area
1	Near Westbrook Drive	264.1	Cropland	
			Summerfallow fields	61
			Stubble fields	23
			Urban	
			Seminary, Parking lot, Road, Ditches, Lawns.	16
2	N. Slope of Rabbit Hill	187.1	Cropland	
			Summerfallow fields	28
			Stubble fields	76
			Urban	
			Road and Residence, Sand Pit	5
			Non-productive woodplot	4
3	S. Slope of Rabbit Hill	159.8	Cropland	
			Summerfallow fields	23
			Stubble fields	70
			Non-productive woodplot	3
			Roadside ditches, Sand Pit	4

TABLE 4 (continued)

Site No.	Location	Total Area In Acres	Land Use	Land Use as Per Cent of Total Area
4	1 Mile N. of Ellerslie Road	113.0	Cropland	
			Summerfallow fields	74
			Forage crops	12
			Road, Ditches	5
			Non-productive woodplot	9
5	Along Ellerslie Road	349.3	Cropland	
			Summerfallow fields	28
			Stubble fields	17
			Improved pasture	9
			Rough grazing	5
			Non-productive woodplot	22
			Intermittent slough	4
			Roads, Ditches, Farmsteads, Experimental plots	15
6	W. Side of Ellerslie U.of A. Farm	182.4	Improved pasture	66
			Forage crops	32
			Roadside ditches	2
7	S. of Automatic Gauge	261.7	Cropland	
			Summerfallow fields	62
			Stubble fields	20
			Non-productive woodplots	6
			Intermittent Slough	3
			Forage crops	9
8	N.W. Corner of Airport	755.2	Cropland	
			Summerfallow fields	12
			Stubble fields	9
			Forage crops	24
			Urban	
			Paved Area	22
			Turf Area	15
			Hangar, Terminal, Lawns	12
			Non-productive woodplot, Sewage Lagoon	6

TABLE 4 (continued)

Site No.	Location	Total Area In Acres	Land Use	Land Use as Per Cent of Total Area
9	W. of Airport	67.2	Cropland	
			Summerfallow fields	98
			Roads and Ditches	2
10	Direct Outlet of Airport	414.4	Forage crops	30
			Urban	
			Paved Area	34
			Turf Area	28
			Terminal, Ditches, Lawns	8
11	Isolated Bush Plot	59.2	Non-productive woodplot	29
			Cropland	
			Summerfallow fields	30
			Stubble fields	51
12	Highway 39 Culvert	347.2	Cropland	
			Summerfallow fields	51
			Stubble fields	16
			Forage crops	24
			Marsh areas, Road, Oil Storage area	9
13	Woodplot in Headwaters	158.4	Non-productive woodplot	95
			Marsh area and Dugout	5
14	Slough Area in Headwaters	956.8	Cropland	
			Summerfallow fields	39
			Stubble fields	19
			Rough grazing	9
			Forage crops	16
			Non-productive woodplot	4
			Permanent slough	8
			Roads, Ditches	5

Source of land use terms: J. B. McClellan, L. Jersak, C. L. A. Hutton. A guide to the classification of land use for the Canada land inventory. (Ottawa: Geographical Branch, Dept. E.M.R., 1967, 19 pp.).

The more relevant terms, extracted from this report, are as follows:

Urban - Land used for urban and associated non-agricultural purposes.
(a) Built up area - All compact settlements; the built-up portions of cities, towns and villages, including any non-agricultural open space which forms an integral part of the urban agglomeration. In most cases, residential use will predominate in these areas. Commercial, industrial and institutional uses will be interspersed and may dominate locally.

Included also: Isolated units separated from compact settlements which are used for industrial, commercial and associated urban purposes.
(b) Mines, quarries, sand and gravel pits - Land used now or in the past for the extraction of earth materials.
(c) Outdoor recreation - Land used for private or public outdoor recreational purposes.

Cropland - Land used primarily for annual field crops of grain, oilseeds, sugar beets, tobacco, potatoes and other vegetables. Fallow land associated with production of any of the aforementioned crops. Land which is in process of being cleared and on which crop production appears imminent.

Improved pasture and forage crops - Land used primarily for improved pasture or for production of hay and other fodder crops. Land used for improved permanent pasture and rotational pasture. Land used for fodder crops; all forage legumes, hay and other forage crops, whether grown for forage or for seed. Land being cleared for fodder production or pasture.

Rough grazing and rangeland - Grasslands such as natural range, including areas of sedges and herbaceous plants. Abandoned farmland and lightly wooded grasslands are included.

Rough grazing land, that is, all tracts of land used for extensive grazing which because of stoniness, shallow soil, poor drainage or drought have not been improved and are not in rotation with field crops.

Areas supporting light or open woodland of little or no commercial value and where grazing is the dominant use, are classed in rough grazing category.

All tracts of land on which grasses, weeds and old hay are the dominant forms of vegetation are included in this category.

Intermittently wet hay-land: swamps and marshes that periodically dry up and are used for grazing or haycutting are also included in this category.

Woodland -
(a) Productive woodland - Land bearing forest of a commercial nature.
(b) Non-productive woodland - Land with a growth of short trees or bushes. Tracts of land where bush and tree scrub cover exceeds 25 per cent. Tree scrub consists of short (immature or stunted) trees, that is, less than 20-30 feet in height.

Swamp, marsh or bog - Open wetlands of all types.
Included in this category are wetlands covered with a swamp, marsh or

muskeg type of vegetation, reeds and other aquatic plants. Another type are intermittent sloughs in which for all but very dry periods the surface is water covered. Water depth is shallow.

Water - Lakes, ponds, rivers and other permanent water bodies large enough to be mapped.

SITE 1: comprises a plot of about 264.1 acres located near Westbrook Drive on 119 Avenue. The types of land use in this sub-drainage basin at the time of the study included summerfallow fields (61%) and stubble fields (23%), a seminary with associated land use (lawns, buildings, parking lot, access road and ditches, 16%). The area is located on the south-western limits of built-up Edmonton. The city will likely expand into this area in the near future. It is thus possible to examine this area as it is now, and then look at its runoff patterns once the city has expanded into the area. Such a study, though, is beyond the scope of the present undertaking. This is a possibility for further research at a much later date.

The variety of land use on this plot, as on several others, gives rise to differences amongst them in moisture storage, snow accumulation and melting. The end product, runoff, is measured at a 36 inch culvert at the plot's outlet, and is applied to the whole area. The Chernozem Soil which covers this sub-basin, as it does most of the Whitemud Creek Basin, has relatively good permeability. In instances where a deficiency exists, the soil absorbs water to achieve the four inch soil moisture storage level used in this study, but this level depends upon the rooting depth of the cover. Depending on this soil moisture storage characteristic, in combination with snow accumulation, temperature and other factors, runoff will generally be small.

The present runoff regime is relatively concentrated, although not as much as it will be when more intensive uses are present. Also the

total yields are moderate but much lower than they probably will be under the more intensive uses. The yield from this heterogeneous area is greater and more flashy than from a non-productive woodland area of the basin. The plot has a large portion (61%) of the area under summerfallow conditions. These bare soils have a considerable effect on snowmelt runoff. Their albedo is very low, and this in combination with the frozen condition of the soils is expected to result in a moderately high yield.

SITE 2: lies on the northern slope of Rabbit Hill. This drainage area is covered by summerfallow fields (28%) and stubble fields (76%), a small non-productive woodplot (4%), a residence and portion of a concession road (5%) totalling 187.1 acres. It is drained by a 36 inch culvert. According to Bowser, et. al., (1962) this plot is located on Chernozemic and Podzolic Soils that are sandy loam in nature. One expects to have a small volume of runoff or none at all due to the textural and structural characteristics of this soil type. These soils are sandy in nature and thus have a low moisture-holding capacity. There is, however, sufficient snow detention by the stubble fields and roadside ditches to provide considerable spring runoff, especially because of the low storage capacity of the surface material. Since the area is on a north-facing hillside, it is expected that differences in runoff, when compared to a south-facing slope, will result. That is, variable snow accumulation, redistribution and losses occur on the slopes due to wind and ablation during the winter. The slope (5-10%) is shallow and thus the aspect effects will not be great. Some variation also occurs from year to year depending upon whether direct radiation or air mass factors are most important in melting the snow. These factors contribute to a variable

runoff pattern from such slopes.

SITE 3: is a sub-drainage area on the southern slope of Rabbit Hill. Its 159.8 acres cover a similar type of land use and soil type as the previous site, (24% summerfallow fields, 70% burned stubble fields, non-productive woodplot 3%, roadside ditches and sand pit 4%). One can anticipate that the melting of snow will begin earlier on this slope (10-15%) than on the north-facing one. Slightly higher amounts of runoff would also occur with a quicker flow. Thus between sites 2 and 3 differences in runoff patterns should result due largely to the effect of aspect.

SITE 4: covering approximately 113 acres of summerfallow fields (74%), forage crops (12%), part of a concession road and part of a non-productive woodplot (14%) is situated one mile north of the Ellerslie Road on the eastern boundary of the basin. This area occupies a part of the Chernozemic Soil zone and similar patterns of soil moisture characteristics are present as in site 1. This area forms a lower portion of drainage for site 5. During a year of heavy snowfall, as in 1971, meltwaters drained from the outlet of site 5 toward the area of site 4. In a year of moderate or light snowfall, only meltwaters from this drainage area are anticipated to flow to the 24 inch culvert at the outlet. This site is expected to yield a moderate amount of runoff, more than a non-productive wooded area, but less than either a summerfallow field or a paved area within the basin. Any rains during the summer are unlikely to produce any runoff from the area, but this depends, among other factors, on the soil moisture storage conditions.

SITE 5: covers 349.3 acres of summerfallow fields (28%), stubble fields (17%), improved pasture (9%), rough grazing (5%),non-productive

woodplots with some conifers (22%), a slough (4%), parts of concession roads, ditches, farmsteads and experimental plots (15%). According to the soil map of Bowser, et. al., (1962) this area is also in the Chernozemic Soil zone. Beneath the woodlot located along the Ellerslie Road, there is an organic ground cover of mosses, lichens and decayed vegetation approximately five inches thick. This layer absorbs much of the moisture for storage and reduces the amount of runoff. Drifting resulted in the accumulation of snow along the peripheries of the woodlots and in the roadside ditches. These areas where snow drifts accumulate provide a small moisture surplus in the spring which runs off later than from adjacent open fields. Snowmelt is quicker from summerfallow fields, pastures and roads, but is slow from the woodlot and from the heavily compacted drifts in ditches. The drifts are anticipated to melt slowly and reduce or prevent the earlier flow of meltwaters from the open fields to reach the culvert outlet. This area probably does not produce a great yield in either a wet or moderate snowfall year, or even during summer rains due to the presence of an organic ground cover.

SITE 6: also drained by a 24 inch culvert, is located on the west side of the University of Alberta, Ellerslie Farm. This drainage plot encompasses 182.4 acres of mostly improved pasture (66%), forage crops (32%) and roadside ditches (2%). The relatively homogeneous cover facilitates comparison with wooded areas, bare summerfallow fields and also heterogeneous areas of this study. Improved pastures and forage crop areas have a higher albedo but less potential evapotranspiration than woodplots. The soil under a cover of grass is also much more compact and usually does not have an organic ground cover like a forest plot. In addition the pasture lands have more limited storage capacities than

forests. Thus this area is expected to have a more concentrated and greater yield than a forested area in the basin. The runoff would also occur sooner than in a woodplot. The area's yield, in any year, depend upon soil moisture conditions, weather elements, snow accumulation and other factors. At times of prolonged summer rains, the area likely yields a moderate amount of runoff.

SITE 7: encloses an area of approximately 261.7 acres of summerfallow fields (62%), stubble fields (20%), non-productive woodplots (6%), an intermittent slough (3%) and forage crops (9%). The plot is located approximately one mile east and one mile south of the automatic gauging station on Whitemud Creek. This drainage area has at its outlet two culverts, each 36 inches in diameter. Here as in site 1, the extent of summerfallow fields (62% of the area) are expected to have an appreciable effect on runoff. The exposed dark soil has a lower albedo and potential avapotranspiration than either forests, improved pastures or forage crops. The yield from this area is anticipated to be greater and more flashy than from a woodland area of the basin. Depending upon the soil moisture conditions before freeze-up and also the amount of snowfall during the winter, this area tends to have runoff in proportion to the prevailing conditions. That is, in a year with heavy snowfall and wet pre-freeze-up conditions and when the soil is recharged, a high runoff results. In a year with drier conditions before freeze-up and a moderate winter snowfall, a small to moderate amount of runoff may result.

SITE 8: occupies approximately 755.2 acres that can be broken into summerfallow fields (12%), stubble fields (9%), forage crops (24%), short-clipped turf (15%) and paved runways of the airport (22%), parking lot, roads, terminal and lawns (12%), and non-productive woodplot and

sewage lagoon (6%). The drainage outlet lies on the northwest corner of the airport property where a 24 inch and a 30 inch culvert drain the area. In this particular plot approximately 37 per cent of the area is covered by paved surfaces and short turf of the airport. This proportion is the main source of runoff in the plot. The paved surfaces have a low albedo, that is, they absorb much of the incoming solar radiation which subsequently causes early melting of snow on the runways, while the drifts adjacent to the runways may have delayed melting. The paved areas also have extremely low infiltration and moisture storage capacities. These characteristics, combined with a significant amount of precipitation, whether snow or rain, is expected to result in faster, flashier runoff and larger yields than from cropland areas, pastures, woodplots or open water areas of the basin. The details of the airport runway drainage are discussed under site 10.

SITE 9: occupies an area drained by a swale on the west side of the airport. It occupies 67.2 acres of primarily summerfallow fields (98%), part of a concession road and ditches (2%). The runoff from this plot was gauged with a small 6 inch sharp-crested 90 degree V-notch weir. This cropland area is located once again on Chernozemic Soils. The low albedo of the dark soil is expected to contribute to a concentrated snowmelt and a moderate yield, higher than from a forested plot and also from a grass covered area of comparable size. This area probably has yields from both moderate and heavy snowfall accumulations and also some minor runoff amounts from extended summer rains.

SITE 10: occupies a large proportion of the Edmonton International Airport property. It is a heterogeneous area which includes forage crops (30%), short clipped turf (28%), runways and other paved

surfaces (34%), main airport terminal, ditches, lawns (8%) totalling approximately 414.4 acres. The major portion of this drainage area is composed of 34 per cent of paved area and approximately 28 per cent of turf area adjacent to the apron and runways.

A drainage working drawing of the airport was obtained from the Department of Transport. With it, a reasonably close delimitation of the drainage areas of both sites 8 and 10 was conducted. This detailed plan contains layout of runways, taxiways, aprons and building area, in addition to contours at a one-foot interval. The plan also contains the entire drainage system and outlines all main and lateral storm pipelines, pipe sizes, direction of flow, gradients, catch basins, inlets, manholes, gutters, surface channels, peripheral and outfall ditches, and other essential drainage features. All natural watercourses are accurately spotted on the drainage working drawing. The drainage system was also planned so that as many of the natural watercourses as possible were used for outfall and rapid removal of the runoff from the airport area. It is the practice at the airport to remove snow from the apron and runways towards the infield turf areas and along the outer edges of the runways. The system of drains quickly removes the runoff from the paved parts much sooner and in a flashier fashion than in an area of forest, cropland, improved pasture or summerfallow fields of the basin.

The paved surfaces have a low permeability. This results in practically no infiltration and moisture storage. Even if some moisture seeps into the ground, from extended melting of the drifts, the system of perforated drainage pipes beneath the runways collect the seepage water and direct it into the natural waterway. This site is expected to

have the earliest runoff. A flashier flow and higher yield than in all other sites of the study area are also anticipated.

SITE 11: is an area of isolated bush located approximately six miles west of Leduc and two miles north from Highway 39, near site 12. This wooded plot has growing on it aspen, some conifers, and other vegetation such as wild rose, grasses, mosses and lichens. The soil is Chernozemic, partly degraded and transitional to Dark-Grey Wooded, having an organic layer of mosses, lichens and decayed vegetation approximately four inches in thickness. This plot covering approximately 59.2 acres is in fact located in a small shallow depression surrounded by summer-fallow fields (30%) and stubble fields (51%). Drifting results in accumulation of snow along especially the northern edge. Due to the relatively poor drainage, the site is expected to produce a small amount of runoff which is considerably less than any other site in the basin. In a year of heavy snowfall and saturated moisture conditions, the site probably has moderate runoff. The yield is likely to be low in a year of low snowfall. During summer rains no runoff probably occurs from this site.

SITE 12: is located approximately six miles west of Leduc on Highway 39 at which point it is drained by a 36 inch culvert. The acreage of this sub-basin totals 347.2 acres. The area consists of summerfallow fields (51%), stubble fields (16%) forage crops (24%) and marsh areas, parts of concession roads, ditches and an oil storage area (9%). It is drained by one main channel. Near its outlet end there exists a wet marshy area which persists for most of the summer. The whole area lies on Chernozemic Soils having a somewhat impermeable layer at some depth. Small local portions of soil in this area were partially

saturated with water before freeze-up. The ensuing snowfall during the winter probably produces considerable runoff, but slow flows are anticipated. This area probably yields some amount of runoff from heavy and moderate snowfall and also from prolonged summer rains.

SITE 13: located in the headwaters of the basin, encloses approximately 158.4 acres of land covered primarily by bush (95% non-productive woodplot, and 5% marsh area and a dugout). This is a small portion of land set aside by the county of Leduc for wild game. The soil of the area is Dark-Grey Wooded and the vegetation includes aspen, some conifers, and a ground cover of mosses, sedges and aquatic grasses. There is also an organic layer present approximately five inches thick in some places. Water balance patterns of this site are similar to those of sites 5 and 11 in that they all receive relatively moderate snow accumulations in the winter. Spring melt is also expected to be similar in all three locations. Runoff is anticipated to occur later, is not flashy and smaller volumes result than in the other sites of this study. Snowfalls in any year are bound to produce some amount of meltwater from the plot, but it is doubtful whether summer rains produce any noticeable amount of runoff.

The site is one of the more densely wooded areas which occur in the basin. Comparison of this site with the others permits evaluation of the significance of plant cover to snowmelt runoff from such areas. It also helps in indicating the type of conditions that were prevalent under more forested conditions at the time of settlement.

SITE 14: is also located in the headwaters of the creek, in an area of Solonetzic Soils. That is, the Solonetzic Soils are prevalent in and near the large depression, but less so on the upland areas of this

sub-drainage basin. These soils may be somewhat impermeable due to the development of a hard, compact, clay-rich sub-soil layer which inhibits infiltration (Toogood and Newton, 1955). The area encompasses approximately 956.8 acres consisting of summerfallow fields (39%), stubble fields (19%), rough grazing (9%) and forage crops (16%), some non-productive woodplots (4%), a large slough (8% of the total area), referred to earlier, and parts of concession roads and ditches (5%). The slough in fact acts as an internal storage basin for runoff waters from the surrounding area in the spring, and during summer it is largely an evaporation basin for water that remained in it from the spring and also for probable local groundwater flow. It is anticipated that runoff will start late, rise quickly to a peak and then decline gradually, and also a moderately high yield results. This area probably produces some amount of runoff in proportion to the annual snowfall accumulation. Depending on the intensity and duration of summer rains, and the moisture conditions of the area, some runoff likely takes place.

Summary of Man's Influence

The activities of man have affected the vegetation of the Whitemud Creek Basin and also the land use patterns. The largest change was caused by cutting and clearing the land for agricultural purposes. The present land use pattern, although established some decades ago, largely influences the runoff regime of the basin.

The main result of man's development of the land in the basin has been a general denudation of the natural landscape, thus altering the water balance patterns; snow removal and accumulation by wind is more pronounced, spring snowmelt is accelerated, and runoff from man-

altered locations is more rapid. In addition to these changes in the landscape, the use of storage capacities would have steadily declined with the result that greater amounts of moisture would have been available for surface runoff. The local runoff patterns will likely undergo more change as further changes in land use takes place. This is especially true for areas where pavements and relatively impermeable surfaces will be present. Additional research is needed to quantify man-induced modification of runoff patterns in the basin. This study can be used for a better understanding of the local runoff patterns.

This chapter was an examination of the land use of the basin. The main characteristics of each site, insofar as these are related to the local snowmelt runoff conditions, have also been outlined. The purpose of the following chapter is to examine the actual runoff that took place in 1972.

CHAPTER IV

SURFACE RUNOFF CHARACTERISTICS

It is the purpose in this chapter to discuss the variables involved in the melting of snow in the Whitemud Creek Basin. The relationship between snowmelt runoff concentrations and streamflow patterns in the Whitemud Creek Basin are also established and examined. The local snowmelt runoff patterns from the sites are also described both quantitatively and qualitatively.

SPRING SNOWMELT

The basic problem in snow measurement concerns the estimation of snowmelt runoff rates and how the resulting flow will affect stream discharge. The snowmelt season has a characteristic runoff pattern. The flows generally increase gradually, reach a peak, and then gradually decrease again for a basin. Within the basin there are many variations from this pattern, partly in response to the variable weather patterns, but largely according to the differences in vegetative cover, topography, moisture conditions and other factors previously noted.

Although the accumulated depth of snow on the basin area is usually light (see chapter two), yield from snowmelt constitutes a significant portion of the total annual surface runoff. The snow only becomes important to the runoff cycle once a gradual build-up in water

supply results from snow detention storage. Depending upon melting patterns, a relatively rapid conversion to and release of water takes place. If melting occurs slowly and gradually, the greatest proportion of the meltwater may be absorbed by the underlying soil. If, on the other hand, melting occurs rapidly, quick flashy runoff conditions can be expected, particularly from some surfaces.

The speed with which a given volume of snow melts depends on the complex interrelations of a number of heat transfer processes and upon the condition of the snowpack. The U. S. Army Corps of Engineers (1956, p. 14) listed the sources of heat energy for snowmelt as:

1) Absorbed solar radiation.
2) Net long-wave radiation exchange between the snowpack and its environment.
3) Convection heat transfer from the air.
4) Latent heat of vaporization released by condensation.
5) Conduction of heat from underlying ground.
6) Heat content of rainwater.

The following sections are discussions of how each of these heat transfer mechanisms affects snowmelt in the study area.

1) ABSORBED SOLAR RADIATION

The amount of solar radiation absorbed by the snowpack is the difference between the amount received and the percentage reflected or albedo of the pack. The amount of solar radiation received at any place depends on several characteristics such as latitude, elevation, angle and direction of slope and a number of others relating to the conditions of the atmosphere and the snowpack.

The latitude of the study area (53^{o} to $53^{o}30'$N) and the sun's corresponding high angle of incidence at the time of snowmelt, greatly influences the amount of incident solar radiation. Much of the literature on snowmelt, for example, for the Eastern U. S. and adjoining Canada,

for Western and Central Europe, located at a lower latitude than the study area, is concerned with relatively low sun induced melting in winter. In these areas an earlier spring also takes place when solar insolation is directly a smaller relative factor. On the other hand, at Yellowknife, for example and in mountainous areas, that are at a higher latitude and elevation respectively, the amount of incident solar radiation is even more important than here.

The latitude of the study area is relatively high, but the time of snowmelt is such (late March and early April), that the sun is higher here (approximately 40^{o}) than it is at the time of snowmelt in a location further south. For example, in mid-January in Boston, the sun at solar noon is approximately 30 degrees above the horizon and the day length is only 9 hours. In Edmonton in early April, the sun at solar noon is over 40 degrees above the horizon and the day length is 13 hours. The lesser cloud cover during the melt period adds to the amount of radiation received by the surface. The increasingly longer hours of daily sunshine is another supplementary positive feature adding to the relative importance of radiation at the time of snowmelt.

The direction and degree of slope of any place on the ground surface affects the quantity of solar energy received by that place. The orientation of south-facing slopes have the longest possible duration of direct sunlight and also the most direct sunlight. In addition to aspect, the steeper the slopes, up to 90 degrees to the sun, the more solar radiation they receive. The altitude of the sun at the time of snowmelt in the basin is approximately 40 degrees. There is a relatively small effect of, for example, a 1 to 3 degree slope to the north or south and thus such areas would receive not greatly

different amounts of radiation intensity. The advantage of a local slope may be overcome or reduced by exposure to intense radiation. The amount of radiation intensity on any surface is greater in bright,sunny than in cloudy periods. It is also greater for dark soils below the snow than for high albedo bases.

Other important variables that modify local radiation budgets are vegetation, land use and cloud cover. The density and type of vegetation cover, through the effect of shading, influences the amount by which the radiation is reduced at the snow surface. In the basin there is a relative lack of shrub and tree cover. This latter fact together with the fact that most of the tree cover is deciduous, leads to decreased effects of shading and thus one might expect an earlier, flashier runoff and a shorter flow duration than in more forested areas. The previously mentioned characteristic also varies within the basin area. For example,the removal of snow from roads and runways in the area exposes dark surfaces that contribute towards earlier melting and a flashier runoff. Also, the redistribution of snow by wind creates conditions where some areas are exposed earlier than others. This fact again contributes towards differences in melt patterns. Forest covered areas in the basin are nonetheless influential in prolonging the presence of snow on the ground, more so than in adjacent open areas.

Cloud cover also reflects and absorbs large and variable amounts of short-wave radiation, thus reducing the amount of energy received by the ground surface. Much of the incoming solar radiation is also scattered by the cloud cover.

The relative amount of solar radiation reflected by a surface such as snowpack is known as albedo. Garstka (1964) found the albedo

of freshly fallen snow to be 0.84. During the melt season however, when the snow was covered by debris and darkened, albedo decreased to 0.40. Jeffrey (1968) noted that freshly fallen snow reflected 85 per cent of the incident solar radiation. He also indicated that for the forest environment, soil colour and land use type tend to affect evaporation and the melting of snow. The darker surfaces have a low albedo and absorb more heat than lighter coloured surfaces. Such variable conditions also are present in the study area and they play a role in the variable snowmelt runoff patterns.

2) NET LONG-WAVE RADIATION EXCHANGE

At the time of snowmelt in the basin, the amount of insolation received by the surface amounts to approximately 600 Langleys per day.[1] Some of the insolation reflected by the snowpack is back-radiated to the atmosphere or forest cover. Under conditions of clear skies heat lost by reflection from the snowpack is generally greater than the heat gained from back-radiation. Conditions under cloudy skies or forest canopies may result in back-radiation being greater or less than that from the snowpack, depending on the ambient air temperature.

Later in this chapter the resulting runoff patterns are examined. The greatest portion of flow occurred during the period March 28 to April 9. Dense cloud cover on these days did not exist and thus did not affect the snowmelt in the area. It is not only cloud cover or the lack of it during the time of snowmelt that may influence

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[1]Langley is a unit of measure of heat energy, one gram calorie per square centimeter. Value of 600 Langleys for the study area was calculated from a graph in G. T. Trewartha, An Introduction to Climate. 4th ed. (New York: McGraw Hill Book Co., 1968), p. 13.

the variable runoff pattern, but also several other variables, the most important of which is temperature, preceding this period. Landals (1970, p. 58) found that cloud cover during peak runoff in the Yellowknife area played a significant role. He stated that considerable long-wave re-radiation results in modifying the difference in rate of melt caused by aspect.

3) CONVECTIVE HEAT TRANSFER

The transfer of heat from the air is of considerable importance in transmitting energy to the snowpack. Both heat and water vapour are transferred to or from the snow by turbulent mixing that depends upon the temperature gradient of the air above it. A downward temperature or vapour pressure gradient results in a transfer of energy to the snowpack. An upward gradient reduces the energy available for the melting or sublimation of snow.

For the Whitemud Creek Basin, the particular air masses which may be present at the time of snowmelt influence the melt pattern. In 1968 the main snowmelt took place in February. This was largely due to the dominance of mild Pacific air masses rather than the cold Polar continental masses normally dominant at that time. Similarly, very cold temperatures may be experienced and snowmelt may be delayed until late April, as happened in 1971. A favourable combination of factors, in any year, is involved at the time of snowmelt.

4) LATENT HEAT OF VAPORIZATION

When water vapour is transferred to the snowpack,it results in a release of latent heat as the moisture condenses. Garstka, et. al., (1958, p. 93) indicated that approximately seven grams of ice can be melted by one gram that condenses. This is due to the great difference

between the latent heat of vaporization of water and the latent heat of fusion of ice. This source of heat becomes increasingly significant with the disappearance of the continuous snow cover as the melt season progresses. Areas of exposed soil and standing water, which increase during the snowmelt period, supply water vapour to the air. This vapour may subsequently condense upon the snow surface and release its latent heat. Although this factor is of greater importance in a more humid region, this source of heat on the snow surface in the study area is of some importance to the melting patterns.

5) HEAT FROM UNDERLYING GROUND

The conduction of heat upward to the snowpack from the underlying ground is very low in spring, when much of the study area is underlain by frozen ground and heat movement from within the earth may be regarded as negligible. This heat can be important for snow that falls in autumn, for soil moisture storage increases and also for the development of ice crusts on the soil surface. This heat is also of some importance indirectly in areas where the snow is shallow and partly transparent. In such instances the low albedo of the ground surface results in conversion of insolation to heat and melting at the snow base, provided the snow above insulates the base snow from colder air temperatures. The melt rates of some areas are affected by the existence of adjacent wooded areas and patches of bare ground which constitute indirect sources of sensible heat.

6) HEAT CONTENT OF RAINWATER

The heat contained in rainwater is transferred to the cooler snowpack. For every degree Centigrade that one gram of water cools, one gram of calorie of heat is supplied to the snow. This amount of heat is

relatively minor considering the normal temperature of rainwater. The U. S. Army Corps of Engineers (Snow Hydrology, 1956, p. 180) suggested that 1 inch of rain at a temperature of 46 degrees Fahrenheit produces only 0.1 inch of melt water.

This heat source can be significant if it is combined with additions from heat of condensation. Rainwater can be more important in the direct sense because detention storage is filled more quickly and runoff may be greatly increased. Little rainfall occurred during the 1972 snowmelt period in the basin and thus this source of heat to snowmelt was not important this year. In many of the past years minor amounts of rain fell, in comparison to the amounts of snow, at the time of snowmelt. Thus even in those years the heat content of rain-water likely played a minor role in the melting of snow, but directly may have contributed to greater runoff.

Conditions of the Snowpack

The amount of snowmelt resulting from a given quantity of heat being added to the snowpack is dependent upon the thermal quality of the snow. The U. S. Army Corps of Engineers (1956, p. 143) defined thermal quality as "the ratio of heat necessary to produce a given amount of water from snow to the amount of heat required to produce the same quantity of melt from pure ice at 32 degrees Fahrenheit". During the melt season, melting at the surface and at the margins of the snowpack often takes place when much of the deeper snow mass is still relatively cold. The snow may also contain some free water that also adds to runoff.

McKay (1964) mentioned that the prairie snowpack is remarkably uniform compared to mountain snowpacks. It does however, vary from one

point to another and regionally. Variations in snow cover at each place are amplified by drifting, and uneven melting which result from differences in elevation, slope, land use, aspect, vegetation cover and other variables. Gray (1968) observed that the prairie snowpack is highly susceptible to wind erosion or redistribution. This process may cause changes in the thermal or reflective properties of the snowpack, in addition to greatly influencing the runoff patterns from an area.

The change that occurs in the snowpack from the time that it accumulates until it melts and runs off is known as ripening or metamorphism (U. S. Army Corps of Engineers, 1956, p. 143). There are many physical processes that contribute to the ripening of snow, including heat exchange by radiation, convection and condensation. Once the liquid content of the snowpack is equal to the liquid-water-holding capacity of the snow, it is said to be ripe and runoff begins to take place.

It must be noted that, due to the local variations in the study area, uniform ripening is less likely than in most deep snow areas.

Applicability of Snowmelt Theories to the Present Study

Although many techniques have been developed for calculating snowmelt under various conditions, these are of little value to the present study. Most of the snowmelt equations are used for flood forecasting; they deal with relatively large areas and are mainly concerned with the timing of peak flow. To apply snowmelt theory to the present study it would be necessary to have a greater amount of micro-meteorological data, as well as an accurate measurement of the area covered by snow at any particular time during the snowmelt period.

An understanding of the energy sources involved in snowmelt is

of definite value to the present study. The preceding sections are discussions of the sources of heat for snowmelt as separate entities. These are in fact interdependent and closely related to such environmental conditions as vegetation, land use, slope, aspect, snowfree areas and open water. Bare ground, water and wooded areas serve as energy exchange surfaces for converting radiant energy into sensible heat. The air in forested plots warms faster than the air over barren open snowfields partly due to the lower albedo of a vegetated surface. Since few exchange mechanisms are present on open prairie areas to convert radiant energy to sensible heat and moisture, such areas can be expected to have a relative uniform flow in time and greater runoff volumes than a forested area. The open areas also do not have shaded surfaces and are more exposed to the direct rays of the sun and warm air masses. Another feature is basal heating and melting which can result in open area snow masses ripening more rapidly through depth than those in wooded areas.

Relationships of Snowmelt Concentrations to Streamflow in the Whitemud Creek Basin

The mean annual precipitation for the basin, over an 89-year period is 17.67 inches. Snow surveys conducted by the Alberta Water Resources Division, within the basin, from 1971 and 1972 indicate that approximately 4 inches or one quarter of the total average annual precipitation is accumulated in the snowpack. This moisture is released quickly as snow melts during the latter part of March and early April. Concentration of one quarter of the year's precipitation into such a short period, when evapotranspiration is low, soil moisture storage may be high and infiltration capacities are low, results in rapid runoff

which makes up a large proportion of the annual streamflow. In most snow-covered regions, this produces a period of peak stream discharge coincident with the period of release.

This characteristic flow tends to be the case for Whitemud Creek. Peak discharge occurs in April and coincides with the period of snowmelt. The creek reached a peak discharge of 547 cubic feet per second on April 7, 1972 (see Appendix E) when snowmelt runoff was well in progress. The flow regime of the creek is not appreciably affected by summer precipitation in most years (see chapter two). It is thus clear that snowmelt runoff is a very important part of the annual water balance in the basin. This has been brought out in chapter two and in Appendix A. The local patterns in the study area resulting from this snowmelt runoff are examined in the following section.

RUNOFF PATTERNS IN THE STUDY AREA

The general environmental conditions in the basin tend to be distinctly related to variations in the pattern of spring snowmelt runoff. To analyze some of the relationships, snowmelt runoff from fourteen representative sites was measured during the spring of 1972 (as described in chapter one). The following sections are descriptions and analyses of the snowmelt runoff data obtained from the sites described in chapter three. In these sections the runoff patterns for the entire snowmelt period and the daily variations in discharge are considered.

Daily flow patterns are not as significant an indicator of site variability in snowmelt runoff as are the flow characteristics over the entire runoff period. Daily patterns nevertheless illustrate a number of interesting relationships. The time of peak daily discharge can be

related to the incoming solar radiation, which in turn is dependent upon slope, vegetation cover and other variables. The time of peak flow may also be related, for example, to the size of the drainage basin. Daily runoff showed prominent peaks in each plot early in the snowmelt period, but flow tended to level off as the melt season progressed.

The dates of flow commencement and termination (or duration of runoff) and the time of peak discharge are also examined in the sections. Some reasons for variations in runoff are discussed, but a more complete discussion of factors that influence local snowmelt runoff follows in chapter five. Some errors which may likely be present in the data are attributed to the inability to measure all of the flow. Among other sources of errors are the poorly delimited divides which made it impossible to precisely measure the areas of the sub-basins.

The runoff period in general lasted for a maximum of sixty days from approximately March 15 to May 15. The period was prolonged for such a time due to the weather. The conditions of the weather, especially during April varied greatly with temperatures during the early part of the month ranging from 20 degrees below normal to 10 degrees above normal. Mild spells were followed by days of rain or snow. One storm on April 21 brought approximately 6.3 inches of wet snow and it further prolonged the runoff period. This trend in the weather becomes quite evident in the examination of the runoff patterns and their graphical presentations on Figures 14A, 14B and 14C. Table 5 is a summary of the snowmelt runoff data from each site.

Site 1

This sub-basin of variable land use (Table 4) produced 2.47 inches of runoff over a period of 41 days (Table 5). The plot ranked

Figure 14A

SNOWMELT RUNOFF HYDROGRAPHS OF REPRESENTATIVE SITES

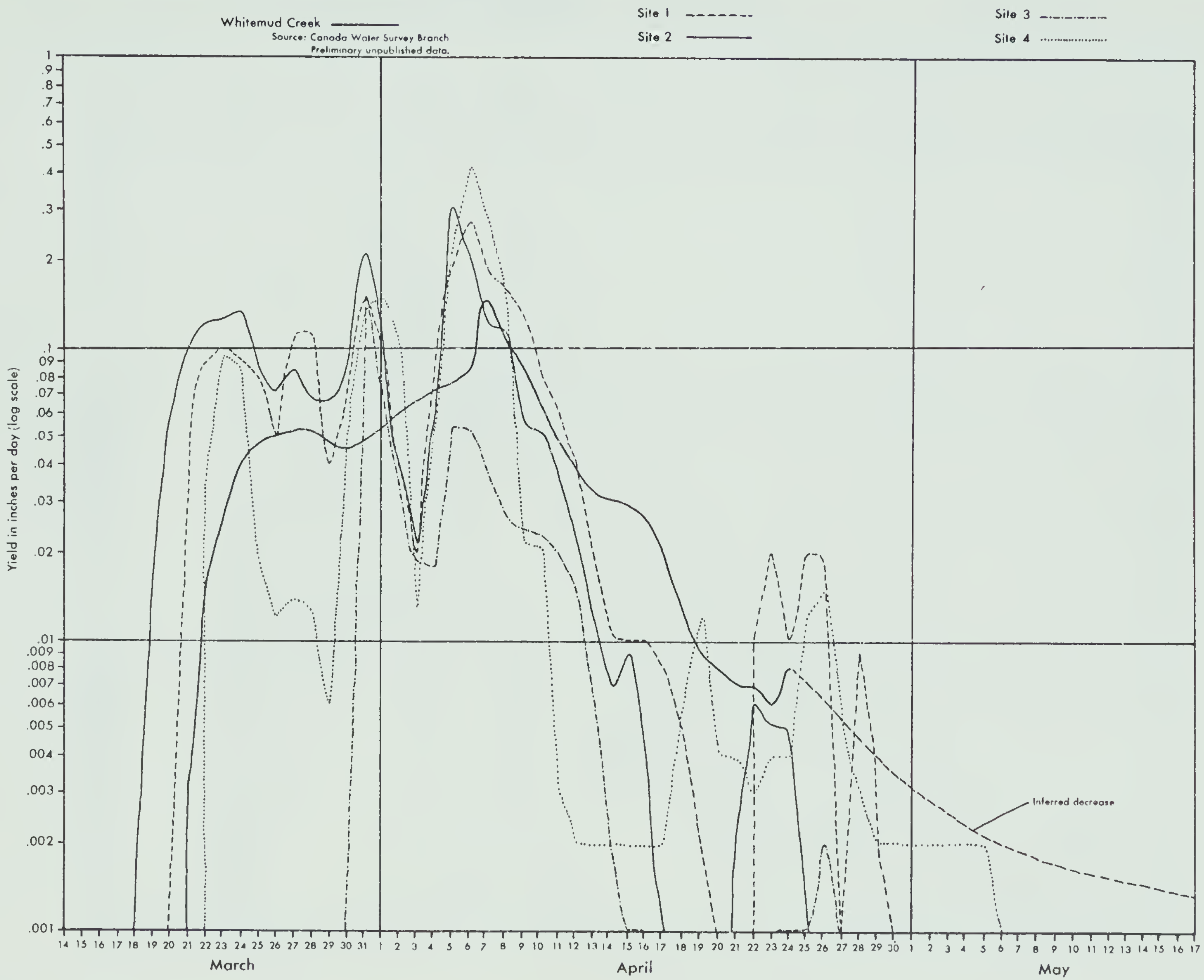

Figure 14B

SNOWMELT RUNOFF HYDROGRAPHS OF REPRESENTATIVE SITES

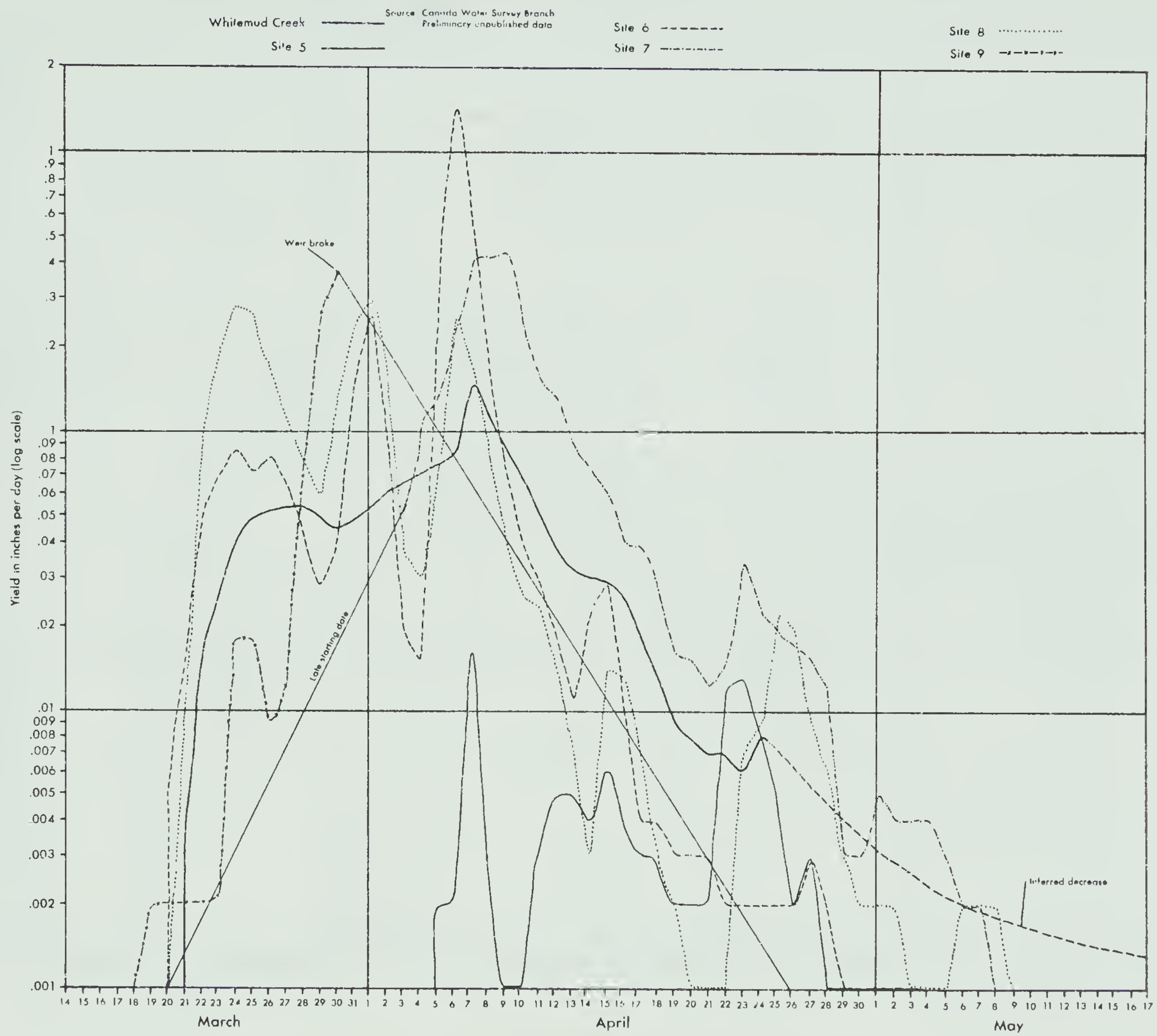

Figure 14C

SNOWMELT RUNOFF HYDROGRAPHS OF REPRESENTATIVE SITES

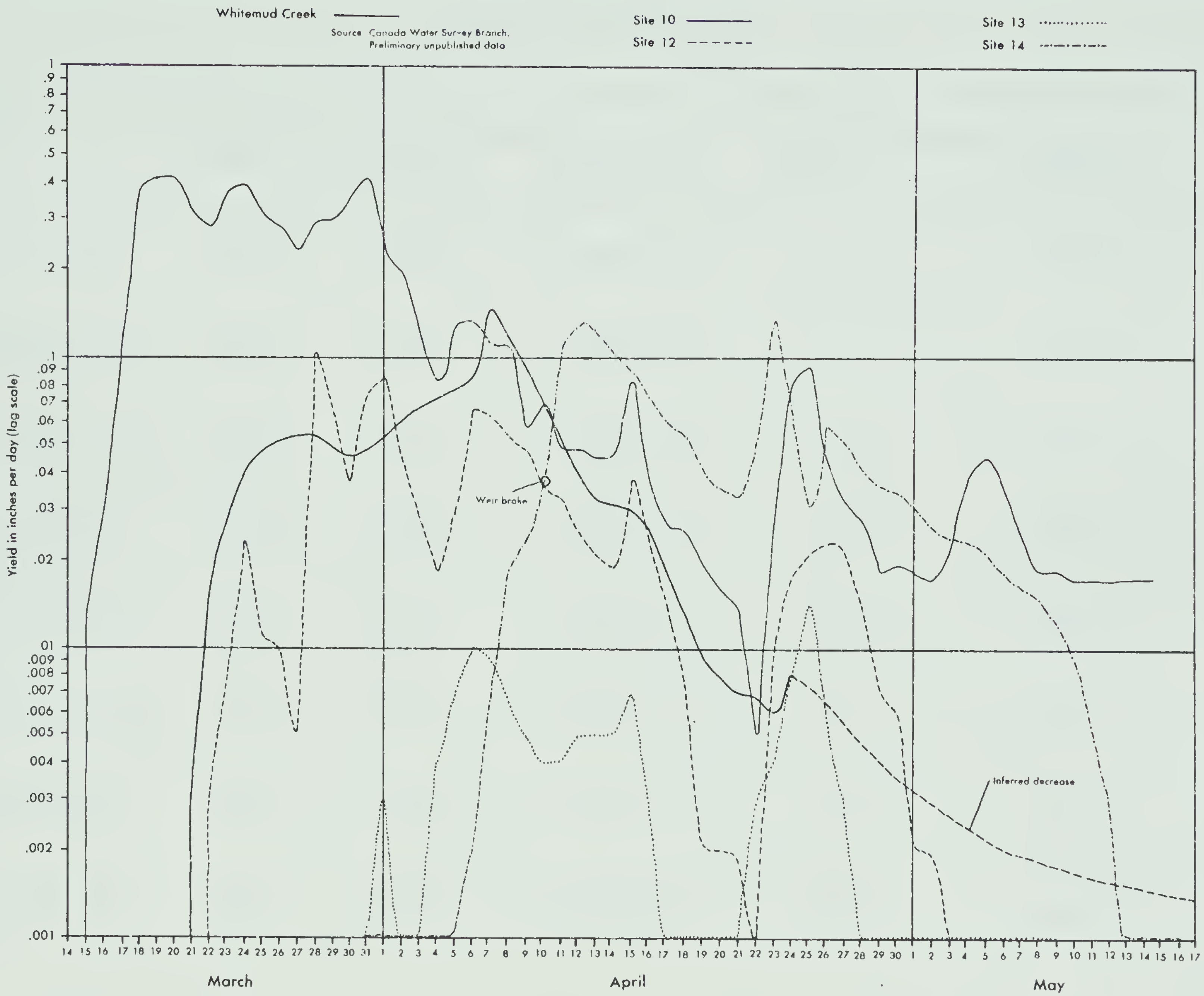

TABLE 5

SNOWMELT RUNOFF DATA

Site Number	Location	Area In Acres	Total Runoff In Inches	Date of First Flow	Runoff Duration In Days	Date of Peak Flow	Flow on Peak Day (Inches)
1	Near Westbrook Drive	264.1	2.47	March 21	41	April 6	0.270
2	N. Slope of Rabbit Hill	187.1	2.39	March 19	39	April 5	0.302
3	S. Slope of Rabbit Hill	159.8	0.55	March 31	29	March 31	0.137
4	1 Mile N. of Ellerslie Road	113.0	1.95	March 22	45	April 6	0.409
5	Along Ellerslie Road	349.3	0.11	April 5	30	April 7	0.016
6	W. Side of Ellerslie U.of A. Farm	182.4	3.89	March 20	41	April 6	1.402
7	S. of Automatic Gauge	261.7	2.81	April 3	37	April 9	0.429
8	N.W. Corner of Airport	755.2	2.92	March 20	52	April 1	0.295

TABLE 5 (continued)

SNOWMELT RUNOFF DATA

Site Number	Location	Area In Acres	Total Runoff In Inches	Date of First Flow	Runoff Duration In Days	Date of Peak Flow	Flow on Peak Day (Inches)
9	W. of Airport	67.2	0.76	March 18	13 Incomplete	March 30	0.357
10	Direct Outlet of Airport	414.4	7.15	March 15	61	March 20	.413
11	Isolated Bush Plot	59.2	-	-	-	-	-
12	Highway 39 Culvert	347.2	1.13	March 22	44	March 28	0.101
13	Woodplot in Headwaters	158.4	0.14	March 31	40	April 25	0.014
14	Slough Area in Headwaters	956.8	1.65	March 31	47	April 23	0.143

Varied from 0.11 - 7.15 inches

Average for all plots 1.99 inches

fifth in total volume of flow, after sites 10, 6, 8 and 7 respectively. The first flow was recorded on March 21 and the last on May 1. Runoff increased slowly from 0.04 inch on March 21 to over 0.10 inch on March 23. From this date the flow first decreased, rose slightly and then decreased again to a low value of 0.02 inch on April 3 (Figure 14A). This trend in the flow pattern,not only for this site, but also others, was attributed mainly to the fluctuating weather conditions. The initial increase in discharge occurred with increased melting due to warm maxiumum daily temperatures. Conversely snowmelt runoff decreased once colder temperatures returned. Runoff increased rapidly from April 3 to a peak discharge of 0.27 inch on April 6 (Figure 14A). Flow on April 6 was 10.9 per cent of the total volume. This rapid rise in flow was due to warm temperatures (in 50's), that preceded this day. After April 6 the flow decreased steadily to zero on April 20. Discharge resumed again late on April 21 when a snowstorm deposited more snow. This second separate runoff period (Figure 14A) lasted for nine days, but produced only minor flows.

The flow from the site usually peaked in late afternoon. The daily variations in flow corresponded closely to the fluctuating temperatures that prevailed. This runoff pattern is also evident for other sub-basin sites as indicated in Figures 14A, 14B and 14C. The flow of the main creek, as indicated by the graph on the three Figures, with basin lag and multiple tributary contributions, was more delayed and uniform than the flows from the sub-basins.

Site 2

This open area (Table 4) also had two separate discharge peaks. The dominant flow occurred from March 19 to April 16, with a secondary

smaller flow duration from April 21 to April 25 (Figure 14A). The first flow from this north-facing slope was recorded on March 19. During the following days from March 21 onwards to April 5 runoff showed a similar trend as in site 1, with flow increases and decreases closely related to varying temperatures. The flow was slow from this plot and runoff started early in the melt period. Peak discharge occurred on April 5 (Table 5), 17 days after runoff started at the site. The amount of 0.302 inch on this day came to 12.6 per cent of the total yield. This volume was considerably higher than that for the south-facing slope. From April 5 to April 16 flow gradually decreased to zero. No flow was recorded from April 17 through to April 20. Runoff started again on April 21 with more precipitation from the late spring snowstorm. This second flow duration lasted for five days and only minor discharges were observed.

Although a slower rate of flow resulted from this site, it did not follow the anticipated patterns mentioned in chapter three. The flow from the site started much sooner and a greater total runoff resulted (2.39 inches) than for the south-facing slope, site 3. Reasons for this discrepancy are discussed in chapter five. The time of daily peak discharge generally coincided with the time of maximum daily temperature, but several hours after peak radiation intensity.

Site 3

Runoff from this south-facing slope, under similar land use as site 2 (Table 4), totalled 0.55 inch (Table 5), which likely is an incomplete amount. Some difficulty was encountered in locating the culvert through the heavily drifted roadside ditches. Once the outlet was located and cleared for measuring, some of the meltwater probably

had already passed through and thus only the remaining amount was measured.

Snowmelt runoff, as far as was measured, occurred over a period of 29 days, from March 31 to April 28. The diurnal pattern indicated that the flow from this site peaked early, at a time when solar radiation was great. This occurred sooner than the time of maximum daily temperature. From initial observations, the start of runoff and peak discharge at this site both occurred on March 31 (Figure 14A). This quick rise in discharge for the site coincided closely with the mild temperatures (upper 40's) that prevailed at that time. A peak flow of 0.137 inch was recorded on March 31; much less than the peak discharge (0.302 inch) for the north-facing slope. From March 31 flow rapidly decreased to 0.018 inch, again coinciding with prevailing cooler temperatures which affected the runoff. With the return of very mild temperatures (55°F) on April 5 and 6, flow increased (Figure 14A). On April 7 cold weather conditions once again prevailed and from this day to April 16 flow steadily decreased to zero. No flow occurred from April 17 to April 23. Then a minor amount of runoff occurred for four days until April 27. This slight rise in discharge was mostly due to an increase in moisture from the snowstorm on April 21. Only very minor flows were recorded at this time because most of the additional moisture was lost to infiltration and evaporation. Thus only very small residual amounts of moisture remained for surface runoff.

The flow from this site was generally slower and also smaller amounts of runoff occurred than that for site 2. The first runoff from the site was noted 12 days after runoff from the north-facing slope started. One reason for the delay for the later start in observations

was due to the beforementioned problem of snowdrifts. This site had the shortest flow duration (as much as was measured) of any of the monitored sites. Although we might have expected earlier melting of snow, higher flow volumes and flashier flow than for the north-facing site, this pattern did not develop. It appears that soil moisture recharge from snowmelt must have been greater for the south-facing than the north-facing slope. Other factors contributing to this difference in flow pattern are discussed in chapter five. It is apparent that the combinations of factors are such that some of the anticipated patterns are not present.

Site 4

Discharge from this plot amounted to 1.95 inches (Table 5). Its land use is indicated in chapter 3 (Table 4). The flow duration lasted for 45 days from March 22 until May 6. Snowmelt runoff at this site started on March 22 and rose briefly on March 23. Flow decreased to a low of 0.006 inch on March 29 (Figure 14A). This decline after the initial rise can be attributed to greater infiltration and ponding of water. Runoff increased slightly for three days with the return of milder weather. Discharge decreased considerably on April 3 once colder temperatures returned, but it quickly rose again to a peak. Peak discharge here was 0.409 inch recorded on April 6 (Figure 14A). This accounted for 21 per cent of the runoff from this plot. From April 6 to April 17 flow decreased gradually. On April 18 a minor increase in flow resulted. This was attributed to flow from a ponded area that was previously blocked by compacted snowdrifts in the roadside ditches northeast of the culvert site. A decrease in flow occurred once again after this date, as indicated on Figure 14A. This decrease resulted

mainly due to infiltration and evaporation losses. With the addition of more snow on April 21, a minor increase in discharge was recorded later on April 26. This delay or lag in flow was caused by snow drifts that obstructed the free flow of water. From April 27 to May 6 flow decreased gradually until it ceased late on May 6.

The daily peak discharge from this site occurred later than the time at which maximum solar radiation intensity prevailed. The variable snowmelt runoff coincided closely to the fluctuations in temperature and weather conditions. The storm in late April did not have a significant effect on increasing the runoff from this site as it did in many other sites. This is further discussed in chapter five.

Reference was made in chapter three that this site comprises a lower drainage area for site 5. The condition of meltwater flowing from site 5 to 4 did not exist this year and separate measurements and calculations for each site were performed. The problem in identifying the contributing area for this site as well as for some others of this study was quite prominent. Runoff may fluctuate considerably due to variation in contributing area within the snowmelt period and also from one season to the next. This characteristic tends to be illustrative of a very large part of the Whitemud Creek Basin. This feature helps to explain why sub-basin unit area yields are probably higher than the whole basin yields.

Site 5

This compound plot of open cultivated fields and bush (see Table 4) produced the lowest amount of runoff (0.11 inch) recorded during this investigation. This was as anticipated in chapter three. Snowmelt runoff from this site started later (April 5) than flow at all

the other sites. Discharge rates were also very slow and small daily volumes of runoff were recorded from the plot. The flow duration lasted for a period of 30 days from April 5 to May 5 (Table 5). The first flow at the outlet was noted on April 5, after all the other sites were already well into their snowmelt periods.

Runoff from cultivated fields and roads actually occurred earlier in the plot but no discharge was recorded at the outlet. The meltwater from upland areas seeped towards the lower wooded area near the outlet where it was ponded over compacted snowdrifts, later absorbed by the snowpack and infiltrated into the soil. The forest cover provided shade for the snow beneath it and this factor combined with the heavy snowdrifts and the depressional terrain results in a large potential for ponding and infiltration before runoff takes place. Discharges were finally recorded on April 5, once sufficient amounts of water had penetrated through the snowdrifts towards the outlet and other moisture requirements had been satisfied.

This site had the second lowest peak discharge (0.016 inch) after site 13, on April 7 (Figure 14B), only 2 days after runoff began. The peak discharge amounted to 14 per cent of the total volume. From its peak on April 7, flow decreased and remained relatively low until April 22 and 23 when it increased slightly due to further additions of moisture from a snowstorm. After these days discharge decreased until flow stopped on May 5. The time of daily peak discharge generally occurred later than the time of maximum daily temperature.

Site 6

Discharge from this relatively homogeneous grassed plot (see Table 4) amounted to 3.89 inches (Table 5). This site had the highest

peak discharge of all the monitored sites, with 1.402 inches of runoff being recorded on April 6 (Figure 14B). Runoff on this day accounted for 36.1 per cent of the total recorded flow from this plot. The first runoff was recorded on March 20, and flow continued for 40 days up to April 29 when it ceased. With prevailing mild temperatures, flow steadily increased to 0.085 inch on March 24. Once cooler weather returned, discharge responded to the conditions and decreased to 0.028 inch on March 29. From March 29 to April 1, flow once again increased. Below average temperaturs over the next three days contributed to decreased runoff. Then on April 5 very mild temperatures caused considerable melting and subsequently flow increased. Peak flow was recorded on April 6. From this day to April 13, discharge steadily decreased. The decrease at this time can be attributed to supply depletion. That is, no contributions of flow from the minor depressions existing in the area took place. Slight increases in runoff were recorded on April 14 and 15 when a minor amount of rain fell. After this event, runoff steadily decreased to zero on April 30.

This site produced the second highest amount of runoff after site 10. The factors contributing to this high runoff are examined in chapter five. The flow pattern resulting from this site was close to the anticipated pattern discussed in chapter three. The daily peak discharge from this plot usually took place at the time of maximum daily temperature.

Site 7

Runoff from this multi-land use plot (see Table 4) amounted to 2.81 inches (Table 5), the fourth highest amount after sites 10, 6 and 8 respectively. Flow from the area took place over a period of 37 days

from April 3 to May 9 (Figure 14B), that is, runoff was monitored at the outlet over this period. It is quite possible that some of the smaller seepages preceding this period were missed. The problem of culvert location due to heavy snowdrifts was also encountered as in site 2. Once observations of flow began, a steady rise from April 3 to April 9 was recorded (Figure 14B). Peak discharge occurred on April 9. Recorded flow on this day was 0.429 inch. This amount accounted for approximately 15.3 per cent of the total runoff from this plot. After this day discharge declined steadily to 0.012 inch on April 21. With the wet snow that fell on April 21 the flow increased slightly to 0.033 inch on April 23. From this day onwards, except for some minor variations, runoff decreased to zero on May 9. The factors causing variations in the runoff pattern from this site are discussed in chapter five.

The flow from this plot was relatively quick. Peak discharge occurred six days after the start of observations. That is, some of the initial runoff was missed due to the previously mentioned problem. The daily peak discharge took place later than the time of maximum daily temperature. The flow patterns that resulted, closely followed the anticipated patterns outlined in chapter three.

Site 8

The runoff pattern from this site, located on the airport property (Table 4), as well as from site 10, was distinctly different from any of the sites. Runoff began on March 20 and lasted for 52 days until May 11 when it stopped (Table 5). From March 20 runoff increased gradually to 0.276 inch on March 24. This rise coincided with a slow warming trend in the weather. Once cold conditions returned, flow also decreased up to March 29. From March 30 to April 1 runoff

increased quickly to a peak of 0.295 inch (Figure 14B). This amount of water was 10 per cent of the total recorded volume. Flow decreased abruptly to 0.030 inch on April 4 because cold temperatures prevailed, ice formed on water surfaces and some snow fell. These conditions led to reduced melting and restricted flow. On April 5 much melting occurred due to above normal temperatures. This subsequently caused greater melting of snow and consequently a rise in discharge over April 5 and 6. Flow then decreased steadily until April 14. With some rain that fell on April 15, a small increase in runoff was recorded. Another slightly higher flow was observed over the period of April 23 to April 28. This increase was due to the snowstorm that deposited approximately 6.3 inches of wet snow on April 21. From April 25 runoff decreased gradually until it stopped on May 11.

The total amount of runoff recorded from this site was 2.92 inches, the third highest volume after sites 10 and 6. Runoff from the site was slightly more flashy and higher daily volumes were also recorded than from all other sites, except site 10. There seemed to be a quick response in this basin to rain, snow and temperature and this was reflected in the flow pattern from this site. The time of daily peak discharge from this site usually occurred later than the time of maximum daily temperature This was attributed to a short lag between warming of the air, melting and observed flow. The foregoing pattern of runoff followed closely the expectations outlined in chapter three.

Site 9

The runoff from this relatively homogeneous site (see Table 4) lasted for approximately 40 days, from March 18 to April 26. Observations of discharge were conducted for 13 days from March 18 to March 30.

From March 30 to April 26 an occasional check on flow was carried out to see how long the runoff period lasted for this site. The discharge at the start was very slow and small volumes were recorded (Figure 14B). Discharge rose gradually to a peak of 0.357 inch on March 30 (Figure 14B). It is impossible to make further comparisons after this day. On March 31 the site was abandoned because repair attempts to the dam were unsuccessful. The time of daily peak discharge from this site coincided closely with the time of maximum daily temperature.

The amount of snowmelt runoff from the area far exceeded the capacity of the small weir. Leakage around the dam was noted on March 30. The presence of mild weather conditions at this time contributed towards rapid melting and quick runoff. On March 31 after attempting to reinforce the dam to control the flow, the site was abandoned because repair attempts were unsuccessful. It is probable that over half of the sub-basin flow was unrecorded.

Site 10

In the previous discussion for site 8, it was mentioned that the runoff from this area was distinctly different. In this instance runoff began very early, on March 15 and lasted for approximately 61 days until May 14 (Table 5). This site had the longest runoff period of any of the monitored sites. Runoff increased rapidly from 0.013 inch on March 15 to a peak volume of 0.413 inch on March 20 (Figure 14C), six days after it started to flow. This volume amounted to 5.8 per cent of the total discharge. Over March 21 and 22 a decrease in flow was recorded. Then a rise occurred until March 24, which was followed again by a decline in runoff until March 27. With a warming trend in the weather, melting of snow increased and consequently discharge also

increased from March 28 to March 31. When extremely cold temperatures returned on April 1, flow decreased to 0.082 inch on April 4 (Figure 14C). April 5 and 6 had once again quite mild temperatures and this subsequently was reflected in the rise of runoff. Then runoff generally decreased until April 15. A slight increase in flow was observed on this day,when some rain contributed to an instant rise in discharge. Flow decreased up to April 22, but on April 23 it increased quickly again due to the moisture that was dropped by the snowstorm on April 21. From April 25 onwards, the flow generally decreased except for minor variations due to small amounts of rain. The observations for the site were terminated on May 14 when flow ceased.

The total amount of runoff recorded for this site amounted to 7.15 inches, the highest volume in this investigation. This volume is actually too high for the amount of precipitation that fell on the basin. The error could be due to difficulty encountered in delimiting the sub-drainage basin, extending the measuring period of the snowmelt runoff too long, problems in measuring and data manipulation. Additional amounts of water may have been contributed initially from non-perforated drainage pipes that cross beneath the airport runways. That is, some of the drainage inlets may have been blocked by heavy drifts that prevented the flow of water and caused ponding. This moisture then seeped towards other outlets, one of which was the selected site. Later in the snowmelt period smaller amounts of seepage water from such drainage pipes may also have contributed to the high volume for this site.

Although there might be an error in the value, it still can be used to indicate the relative importance of large paved areas to the runoff patterns in the basin. The discharge from the site was flashy

and a large volume resulted. The time of daily peak discharge from the site occurred later than the time of maximum daily temperature. This characteristic flow pattern can be explained by a short lag in flow, from the time of peak solar radiation to the time when higher discharges are noted at the outlet. These runoff patterns closely followed the anticipated patterns mentioned in chapter three.

Site 11

This wooded site (Table 4) produced extremely small volumes of runoff which were observed only in a qualitative manner. No distinct drainage channel was evident at the time the site was selected. Only minor seepages contributed to flow, and then only from the heavily drifted areas along the northern edge of this wooded site. Some additional amounts of water seeped towards the lower depression from the open cropland areas. Most of this moisture, plus an amount from the drifts was used in recharging soil moisture storage in this depressional forest site and subsequently surface transfer was neglibible. Although runoff ceased from several other sites, this site was not completely devoid of snow until the beginning of May.

Site 12

This drainage area produced 1.13 inches of runoff over a period of 44 days (Table 5). The first flow was recorded on March 22 and the last on May 4. Runoff increased quickly over the first three days, then declined briefly again until March 27. Then suddenly on March 28 flow increased rapidly to a peak of 0.101 inch (Figure 14C). This volume amounted to 8.9 per cent of the total recorded volume. This rapid rise in runoff was due to the removal of drifts that blocked the free flow of water at the site. From March 28 to 30 melt runoff decreased

again, but over March 31 and April 1 it rose once again. The latter two days on which discharge increased coincided with mild temperatures that contributed to quick snowmelt and greater runoff. Once colder conditions returned again, melting decreased and consequently the flow volumes recorded at the outlet also decreased over April 2, 3, 4 and 5. On April 6 and 7 mild temperatures prevailed and the increased flow was attributed to this warm trend. From April 8 onwards to April 14, the flow steadily decreased. With some rain that fell on April 15, runoff increased slightly, but dropped again afterwards just as quickly as it rose. A slight lag of two days occurred at this site between higher discharge and the day when the wet snow was deposited. Flow increased on April 23, rose to a peak of 0.023 inch on April 26, and then decreased steadily until it stopped on May 4. A closer examination of the factors influencing the flow pattern is presented in chapter five.

Site 13

Runoff from this forested location (see Table 4) totalled 0.14 inch, the second lowest amount after site 5 (Table 5). Snowmelt runoff occurred over a period of 40 days from March 31 to May 9. In general, the volume of discharge and the resultant flow pattern closely followed the expectations mentioned in chapter three. Snowmelt was slow and runoff started considerably later than in some of the other sites of this study. The daily volumes of discharge were also the smallest of any of the sites.

The first flow was noted on March 31 after the flows from most other sites were well in progress. With mild temperatures that prevailed on March 30 and 31 the snowpack ripened relatively quickly and runoff started. From March 31, flow increased briefly on April 1, but then

decreased again under the influence of colder weather (Figure 14C). Over April 4, 5 and 6 a slight increase in flow was recorded. This rise was,once again attributed to the return of mild temperatures. On April 6, the runoff reached one of the high peaks of 0.010 inch during the flow duration. From April 6 to April 21, the flow generally decreased with the exception of some minor flow variations on some days due to milder temperatures, rain or a combination of factors. The flow increased steadily from April 22 until it peaked on April 25. This late increase and peak was due to the April 21 snowstorm which contributed additional moisture. The site had the lowest peak discharge of any site, with 0.014 inch being recorded on April 25 (Figure 14C). This peak occurred late in the snowmelt period of this site. The reason for this late peak is discussed in chapter five. From April 25 flow decreased as quickly as it rose and from April 28 to May 9 the site produced a consistently very low flow (Figure 14C). Runoff ceased on May 10. The diurnal fluctuations in flow indicated that the daily peak flow occurred much later than the time of maximum daily temperature. This flow characteristic was again due to a lag between warming of the air, melting of the snowpack and flow.

Site 14

Discharge from this sub-basin area, in the headwaters (Table 4), amounted to 1.65 inches (Table 5). The first runoff was recorded on March 31, and flow continued for 47 days up to May 16 when it ceased. Runoff started slowly and initially was measured by a 90 degree V-notch weir. From April 6 to April 12 flow steadily increased. On April 10 the pressure of the ponded water behind the weir caused it to give way and reinforcement attempts were unsuccessful. The site was consequently

abandoned. The remaining observations were collected from a culvert located one mile north along the same channel. Since the snowmelt runoff period had just started at the site and no flow was noted previously at the culvert, only small adjustments in data were necessary. From April 12 until April 21 flow steadily decreased. Then on April 22 runoff peaked to 0.143 inch (Figure 14C). The volume on this date accounted for 8.6 per cent of the total recorded volume from this plot. This increase was partly attributable to the snowstorm of April 21, and partly to the fact that there was still much flow from the site at the time. The runoff decreased gradually after April 23, but a slight rise was recorded on April 26 due to some rain. The daily peak discharge usually occurred later than the time of maximum daily temperature.

PHYSICAL AND CHEMICAL PROPERTIES OF SNOWMELT

This final section deals with the examination of the quality of water derived from the basin during the snowmelt runoff period. Forty surface runoff water samples were collected and were analyzed with a HACH kit as mentioned in chapter one. The samples were analyzed for several physical properties and chemical constituents (temperature, turbidity, colour, pH, Iron, Chloride, Alkalinity, Phosphate, Sulphate and Hardness), to relate the relative qualities of surface runoff water to various environmental conditions. These samples were collected at each of the representative sites. This sampling procedure was implemented with the purpose of identifying some general qualities of runoff water in relationship to the local land use. Additional samples were collected from the main creek channel at approximately two mile intervals, at convenient bridge crossing points. All the samples were collected by

simply dipping a glass container into the main flow and catching a representative amount. The analyses of the samples, as presented in Tables 6 and 7, show some of the dissolved mineral content of the water, but do not indicate whether a water that is reported to be chemically potable is bateriologically safe. Tables 6 and 7 list some of the varying degrees of physical properties and chemical components of melt-water present at different times of the snowmelt period.

Chemistry of Flow

Water is a very complex chemical substance which comes into intimate contact with a vast number of different components that have a wide range of physical and chemical properties. During its flow, whether above or below the ground surface, it is also subjected to a very wide range of time, temperature and pressure conditions. This means that the longer water, especially groundwater, is in contact with certain mineralogical materials, the closer its chemical composition will relate to these materials.

Pure water is comparatively inactive. The chemistry of natural water depends on temperature, pressure, acidity or alkalinity and dissolved ions. All naturally occurring water contains some mineral matter dissolved from earth materials with which water has come in contact. In addition, some streams in urban areas may contain some sewage effluent. Such a condition though is absent along the lower course of Whitemud Creek where it passes through built-up areas of Edmonton.

On the built-up areas adjacent to the creek there exist separate sewer systems, one for stormwater and snowmelt and one for sanitary (domestic) sewage. Outlets for stormdrains are in the creek valley. It is unlikely that the quality of runoff water is seriously damaged, but poorer

TABLE 6

CHEMICAL CONSTITUENTS OF RUNOFF WATER DURING INITIAL SNOWMELT PERIOD

Site No.	Location	Temp. °C.	Turbidity Jackson Units	Iron ppm	Colour APHA Pt Co Standard	Chloride ppm NaCl	pH	Alk. ppm $CoCO_3$	Phosphate ppm	Sulphate ppm	Total Hardness ppm $CaCO_3$
1	Near Westbrook Drive	7	55	0.08	190	15	7.9	50	1.40	65	80
2	N. Slope of Rabbit Hill	9	200	0.05	380	10	8.0	30	1.80	15	50
3	S. Slope of Rabbit Hill	5	20	0.02	35	10	8.2	30	1.10	5	10
4	1 Mile N. of Ellerslie Road	6	40	0	220	20	6.8	140	0.05	18	100
5	Along Ellerslie Road	7	35	0	195	10	9.5	100	1.50	20	50
6	W. Side of Ellerslie U. of A. Farm	7	60	0	250	5	5.3	100	0.38	20	70
7	S. of Automatic Gauge	8	100	0.01	280	10	8.5	60	0.20	80	110
8	N.W. Corner of Airport	9	35	0.05	130	15	6.9	50	0.40	31	70

TABLE 6 (continued)

CHEMICAL CONSTITUENTS OF RUNOFF WATER DURING INITIAL SNOWMELT PERIOD

Site No.	Location	Temp. °C.	Turbidity Jackson Units	Iron ppm	Colour APHA Pt Co Standard	Chloride ppm NaCl	pH	Alk. ppm $CoCO_3$	Phosphate ppm	Sulphate ppm	Total Hardness ppm $CaCO_3$
10	Direct Outlet of Airport	7	30	0.02	85	15	8.4	90	1.40	18	80
12	Highway 39 Culvert	8	35	0	130	30	8.4	60	0.41	11	50
13	Woodplot in Headwaters	5	30	0.08	190	15	7.2	50	0.35	20	50
14	Slough Area in Headwaters	6	40	0.10	210	15	7.0	80	0.60	11	80

TABLE 6 (continued)

CHEMICAL CONSTITUENTS OF RUNOFF WATER DURING INITIAL SNOWMELT PERIOD

MAIN CREEK SITES

Site No.	Location	Temp. °C.	Turbidity Jackson Units	Iron ppm	Colour APHA Pt Co Standard	Chloride ppm NaCl	pH	Alk. ppm $CoCO_3$	Phosphate ppm	Sulphate ppm	Total Hardness ppm $CaCO_3$
1	Mouth on N Sask. River	8	110	0.95	320	25	7.8	90	0.60	25	100
2	45 Ave. storm sewer outlet in Rainbow Valley	10	500+	1.10	500+	30	8.7	100	0.85	100	130
3	25 Ave. Bridge	6	95	0.20	310	20	7.6	80	1.30	28	60
4	C.W.S. gauge	9	60	0.10	220	15	7.7	70	1.15	25	60
5	Nisku Road	7	60	0.08	200	15	7.6	80	1.05	21	60
6	Hwy. 39	7	50	0.05	195	15	7.8	90	1.05	25	80
7	Near Ireton	6	50	0.10	220	15	7.1	70	0.75	25	60
8	Kavanagh Road	5	90	0.10	220	15	8.5	90	0.70	22	80
9	N of large slough	8	65	0.05	210	10	7.9	80	0.95	20	70

TABLE 7

CHEMICAL CONSTITUENTS OF RUNOFF WATER DURING HIGH SNOWMELT

Site No.	Location	Temp. °C.	Turbidity Jackson Units	Iron ppm	Colour APHA Pt Co Standard	Chloride ppm NaCl	pH	Alk. ppm $CoCO_3$	Phosphate ppm	Sulphate ppm	Total Hardness ppm $CaCO_3$
1	Near Westbrook Drive	15	60	0.10	220	15	7.8	60	1.10	60	80
2	N. Slope of Rabbit Hill	17	155	0.70	500+	15	8.2	60	1.40	20	70
3	S. Slope of Rabbit Hill	14	40	0.10	170	10	8.1	50	0.95	5	40
4	1 Mile N. of Ellerslie Road	17	50	0.05	200	15	8.0	80	0.75	20	180
5	Along Ellerslie Road	15	35	0	210	10	7.7	80	1.50	15	100
6	W. Side of Ellerslie U. of A. Farm	18	80	0	280	10	8.1	80	0.40	20	70
7	S. of Automatic Gauge	15	120	0.05	300	10	8.2	70	0.35	100	70
8	N.W. Corner of Airport	19	45	0	140	15	8.5	120	0.18	35	190

TABLE 7 (continued)

CHEMICAL CONSTITUENTS OF RUNOFF WATER DURING HIGH SNOWMELT

Site No.	Location	Temp. ° C.	Turbidity Jackson Units	Iron ppm	Colour APHA Pt. Co Standard	Chloride ppm NaCl	pH	Alk. ppm $CoCO_3$	Phosphate ppm	Sulphate ppm	Total Hardness ppm $CaCO_3$
10	Direct Outlet of Airport	12	35	0.10	90	10	8.4	130	0.12	15	140
12	Highway 39 Culvert	13	95	0.40	380	15	7.9	60	0.15	20	40
13	Woodplot in Headwaters	12	30	0.10	190	15	7.1	40	0.28	20	30
14	Slough Area in Headwaters	13	40	0.30	210	15	7.1	70	0.45	15	80

TABLE 7 (continued)

CHEMICAL CONSTITUENTS OF RUNOFF WATER DURING HIGH SNOWMELT

MAIN CREEK SITES

Site No.	Location	Temp. ° C.	Turbidity Jackson Units	Iron ppm	Colour APHA Pt Co Standard	Chloride ppm NaCl	pH	Alk. ppm $CoCO_3$	Phosphate ppm	Sulphate ppm	Total Hardness ppm $CaCO_3$
1	Mouth on N Sask. River	8	165	0.80	480	15	8.5	110	0.40	35	120
3	25 Ave. Bridge	15	105	0.60	390	20	8.5	100	0.50	35	100
4	C.W.S. gauge	13	90	0.55	380	20	8.4	80	0.25	30	80
5	Nisku Road	12	75	0.10	220	20	8.2	90	0.30	20	80
6	Hwy. 39	13	65	0.50	290	15	8.2	80	0.35	25	70
7	Near Ireton	10	65	0.25	250	15	8.5	80	0.25	25	70
8	Kavanagh Road	8	105	0.35	250	15	8.6	90	0.25	20	80
9	N of large slough	8	75	0.05	220	10	8.5	90	0.30	25	70

quality of runoff water results from the more built-up areas (Table 6).

Significant runoff began flowing from the storm drain in the Rainbow Valley near 45 Avenue on March 11. This early date in itself is indicative of the effect a built-up area of a city has on snowmelt runoff. The analyses of water collected at this outlet (Table 6) show that it contained many more chemical constituents than other less developed areas.

Physical Properties of Snowmelt Water

The first column of Tables 6 and 7 indicates the temperature of the water sample. The most significant difference in temperature at the time of initial runoff was observed in the water from the storm sewer in Rainbow Valley (Table 6). The temperatures of all samples during the second sampling period was also generally higher than at the time that runoff started.

Turbidity in water is caused by the presence of suspended matter, such as clay, silt, finely divided organic matter and other microscopic particles. The degree of turbidity is an expression of the optical property of a sample causing scattering of a light beam and also absorption rather than transmitting the beam in straight lines through the sample. Turbidity values varied widely in all samples at both times of sampling. The lowest value was recorded from site 3 (south-facing slope) and the highest from the storm drain in Rainbow Valley (Table 6). Turbidity slightly increased in some samples at the second sampling period (Table 7). Greater increases were observed at sampling points on the main creek.

The turbidity varied widely due to the conditions at the sites. In some instances where frozen ground existed at the initial sampling

period, for example sites 3 and 12, low turbidity values were observed. Later, once the soil thawed, the water picked up fine soil particles and held them in suspension. Thus at the second sampling period increases in turbidity were noted from these sites and others. The main creek also indicated small increases in turbidity. This is attributable to greater tributory contributions of suspended materials and also to the main creek flow eroding the channel along its path.

Colour in water may result from the presence of natural metallic ions (Iron and Manganese), humus and plant materials, weeds and industrial wastes. The colour of the samples during both times of sampling varied widely. Initially the colour varied from a low value of 35 units for site 3, to a high value of 500+ units for the storm drain in Rainbow Valley. At the second sampling period, the units of colour were higher than at first. This is also attributable to the fact that with a higher flow more materials are carried by the runoff water.

The pH in most natural waters falls in the range between 4 to 9. The majority of waters are slightly basic due to the presence of carbonate and bicarbonate. All of the collected samples had a pH which fell in the 4 to 9 range. The pH values increased slightly at the time that secondary samples were collected.

The pH of water is affected to some extent by the temperature, and also the carbonate content. Thus with slightly warmer water at the second sampling period, increases in pH were observed.

Chemical Properties of Snowmelt Water

Natural waters contain variable but minor amounts of Iron. The majority of the samples collected for this study contained some amounts of Iron at both times of sampling. The highest amount of Iron

(1.10 ppm) was observed in the water of the storm drain in Rainbow Valley (Table 6).

Chloride is one of the major anions in water and sewage. All the samples at both sampling times were found to contain some Chloride ions (Tables 6 and 7). On the average, samples contained 15 parts per million (ppm). Slightly higher values of 30 ppm were observed, at the time that the first samples were taken, from the culvert site on Highway 39 and also from the storm sewer outlet in Rainbow Valley (Table 6).

The Alkalinity of water is usually due to the presence of bicarbonate, carbonate and hydroxide components. The Alkalinity of the samples generally increased slightly from the first time of sampling to the second one. Alkalinity varied from 30 ppm $CaCO_3$ for sites 2 and 3, to 140 ppm $CaCO_3$ for site 4.

The Phosphate component occurs in traces in many natural waters. Waters receiving raw or treated sewage,agricultural drainage and certain industrial waters normally contain significant concentrations of Phosphate. The highest amount of Phosphate in this study was noted in the water from site 2 (Table 6), and the lowest in the water from the site on Highway 39. The Phosphate values tended to decrease in water from the beginning of the runoff period to the later time of sampling. On further examination of Tables 6 and 7 it can be shown that the cropland areas, for example of sites 1, 2, 3 and 5 had probably been fertilized the previous summer. Thus higher values of Phosphates were observed from these sites.

The Sulphate ion is widely distributed in nature. It may be present in natural waters in various concentrations. The Sulphate content remained relatively constant in all samples at both times of sampling.

A high value of 100 ppm was observed in water from the storm sewer in Rainbow Valley.

The Hardness of a water is defined as the characteristic of water which represents the total concentration of just the Calcium and Magnesium ions expressed as Calcium Carbonate ($CaCO_3$). Values of Hardness for this study varied from a low of 10 ppm $CaCO_3$ for site 3, to a high of 190 ppm $CaCO_3$ for site 8. Hardness on the whole increased slightly for most samples from the time of first sampling to the second sampling period. These slight rises in Hardness may be attributable to some interflow water containing greater concentration and seeping into the natural channels.

Summary

The general characteristics of the quality of runoff waters in the basin have been briefly discussed. From the forty analyses presented in this study it is somewhat difficult to relate water qualities to environmental conditions. In order to establish much closer relationships between the quality of water and a specific land use, a more detailed sampling programme and laboratory testing procedure is necessary. Very preliminary conclusions, based upon the observations, may be reached.

Water derived from urban runoff in the lower course of the main creek generally contains more chemical components and also has the most objectionable physical properties.

The water quality of the main creek tends to deteriorate as it passes through the basin from the headwaters to the mouth. Along its path many tributaries contribute constituents, which they have collected from different land use areas, which all contribute to a decreasing

quality of the water.

Agricultural areas in the basin also tend to contribute quantities of chemical constituents to the creek's water. Such constituents as Phosphates and Sulphates were especially noted.

Natural water areas and marshy sections within the basin contribute water which is slightly acidic.

As a tentative conclusion it is possible to state that, by most urban standards, the spring snowmelt runoff of this basin is of relatively good quality.

CHAPTER V

A DISCUSSION OF SNOWMELT RUNOFF PATTERNS

In the previous chapter, the characteristics of the snowmelt runoff patterns from fourteen sample plots in the study area were described. It was indicated generally in that chapter that, the weather conditions during this year's snowmelt runoff period greatly influenced melt patterns. In the present chapter, some of the environmental factors of the sites are analyzed. This is done to assess their role in the variable runoff patterns in the basin. It is not intended that all factors be discussed in depth for each site; only the more relevant ones for each site.

Snowmelt runoff from open land (cropland, pasture and paved areas), given similar location, climate and other conditions, generally exceeds that from forest land. The wooded plots occupying an area to the fullest, having low albedo, deep root system and perennial foliage use more water than agricultural vegetation.

ASPECT

Sites 2 and 3

Aspect is an important factor, in areas having significant topographic expression, in contributing towards local variation in runoff as the snowmelt period advances. Two of the fourteen sample plots

exhibited runoff characteristics which tended to be attributable to slight differences in aspect.

Sites 2 and 3, under similar land use (see Table 4), vegetation cover and soils, but of opposing aspect (north- and south-facing), had markedly different snowmelt patterns in terms of start of flow, duration and volume of flow, daily peak flow and time of peak discharge. The south-facing area (site 3) contributed very little runoff (0.55 inch), while the north-facing area (site 2) produced a greater amount (2.39 inches). The higher runoff of site 2 can be attributed to a number of factors. The snow cover on this plot, from field observations, tended to be thicker than on the south-facing plot and consequently had a higher water content. The snow cover of site 2 was north-facing and thus was not subjected to as great a sublimation and evaporation* loss as the south-facing plot. Other conditions such as degree of slope, (5-10% for site 2 and 10-15% for site 3), surficial material and cultivation were also similar for each site. Thus the main cause for the differences in sublimation and evaporation (particularly during the snowmelt period) tended to be solar radiation. This factor should account for the variation in the amount of runoff.

Snowmelt on the south-facing site began on March 31 (Table 5) and patches of bare soil were soon exposed. These dark patches, having much lower albedo than the snow, influenced the local melting of snow

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*Jeffrey (1968) stated that direct evaporation loss from the snowpack is small, and accounts for less than three per cent. During snowmelt, however, there may be a substantial water loss through evaporation where water is held as a thin film on low-albedo surfaces.

around them. Moisture released from the remaining snowpack spread out over the patches of bare soil. Much of this moisture was then lost to evaporation and some to infiltration because of the low albedo and subsequent warming of the exposed soil. (Such warming would be very slow on a north-facing slope such as site 2 and would result in little losses of water).

Water that was released during the initial stage before March 31 was insufficient to produce noticeable amounts of runoff and was detained in the snowpack, roadside ditches and shallow depressions of the surface. Once the snowpack had ripened further, meltwater began flowing and in such noticeable amounts that a peak flow was recorded on March 31 (Figure 14A). During the early stage of snowmelt, some slight seepages may have occurred through the culvert outlet. Such seepages could not have been considerable however, due to the heavy compacted drifts at the inlet and also the rapidly fluctuating weather conditions that reduced movement of water.

Considered over the entire runoff period, the two sites produced different flow and the duration of melt was also substantially different. Runoff from the south-facing slope (site 3) lasted for 29 days, whereas discharge from the north-facing slope (site 2) was measured over a 34-day period.

VEGETATION COVER

It was previously discussed in chapters two and three that vegetation plays an important role in snowmelt runoff. From data collected in this study it is possible to relate runoff variations to differences in plant cover in the study area. The following plots

(sites 5, 6, 11 and 13) are ones in which significant different runoff patterns resulted. These differences are attributable to the plant cover at these sites. These sites will be dealt with separately to determine why variations in flow resulted.

Vegetation cover is an important indicator of the annual moisture balance of a site. The soil moisture regime of most locations is reflected by the type of vegetation present at a site. In turn, the soil water at a locality is dependent upon the nature of the mineral soil and presence or absence of organic material. The latter characteristic tends to have a greater influence upon infiltration patterns than does the existing vegetation.

Site 5

This site, covering 349.3 acres of compound land use (see Table 4) yielded the lowest amount of runoff (0.11 inch) of all the sites investigated. It was mentioned in chapter four that flow duration lasted for 30 days, from April 5 to May 5 and during that time small flow volumes were recorded.

Runoff from the bare summerfallow fields and roads started several days sooner, on March 31. The meltwater from these areas flowed along the roadside ditches towards the culvert at the outlet of this plot. Due to the shading by trees in the woodplot and also the compaction of the snowpack in the ditch from continuous road clearing, the water travelled along the top of the drifts in this stretch and became ponded. Most of this water did not reach the outlet. Much of it was absorbed by the snowpack and infiltrated into the organic layer where it was stored. This is possibly the more important factor why this area produced such a small amount of runoff. The organic layer

absorbed much water and helped to reduce the amount of runoff from this plot. Later in the snowmelt period flow took place towards the culvert from the east and west.

The albedo, in addition to the shading effect by the deciduous trees, delayed the melting of the snowpack beneath the wooded areas. The albedo of the bush plots influenced the timing of peak daily discharge. The vegetation tended to absorb much radiant energy during the day. This heating is confined largely to the upper levels of the forested plot and the shade provided to the lower levels more than conpensates the melting during the day. The shading effect of the vegetation reduces melting of the snow by direct radiation. Thus melting was dependent upon the temperature of air and a lag in flow resulted from a lag pattern in warming of the air. This characteristic flow was noted for site 5 as well as for site 13. Although the runoff from the site ceased on May 5 it was not completely devoid of snow until several days later.

Site 6

This site represents another land use type, with a different vegetation type, that of grass cover (Table 4). This area of approximately 182.4 acres produced 3.89 inches of runoff, the second highest amount after site 10. This volume was also much greater than that for the forested plots of sites 5, 11 and 13. Runoff from this site started on March 20, much earlier than from any of the wooded areas (see Table 5).

This site was very open with minor depressions and the snowpack was subjected to much redistribution and compaction and also suffered from sublimation and evaporation losses. Although such

conditions prevailed at this site, it yielded a large volume of water when compared with the forest plots (sites 5, 11 and 13) and even the bare summerfallow plots (sites 1, 4, 7 and 9).

Another factor that contributed to the runoff patterns is the condition of the soil. The soil at this site was much more compact and was not as permeable and porous as the loose organic material on the surface of the wooded areas. Not much water could infiltrate into the soil and become soil moisture storage. Subsequently considerable amounts of moisture remained for surface runoff. Since the area did not have any large trees to shade the snowpack, all of the solar radiation was absorbed by the pack. The last few days of lower discharge rates resulted from slow melting of snowdrifts in the eastern roadside ditch. This occurred at a time when the rest of the area was already bare of snow. In addition, the soil had thawed to a greater depth and some of the meltwater infiltrated into the soil at this time.

Site 11

This plot, covering approximately 59.2 acres (Table 4), produced a very low amount of runoff, which if it would and could have been measured, would approach the amounts of sites 5 and 13. The site is located in a depression which has an organic layer four inches thick. This resulted in extremely low flows this year. Runoff started quite late from this plot (April 5). This was partly due to the shading effect of the vegetation and the moisture absorption properties of the organic material. Heavy drifting occurred along the northern edge of this plot. Any meltwaters that resulted, flowed towards the depression, became ponded on the still frozen ground and as the snowmelt period progressed, infiltrated into the organic layer. Seepage waters from

the drifts were observed at a time when other sites were dry. In this site as in sites 5 and 13 the flow duration (internal within the sub-basin, not external from it) was prolonged due to the shading effect of the trees.

<u>Site 13</u>

This area of a more forested part of the basin encloses 158.4 acres of primarily aspen woodlot. The first runoff from this area was noted on March 31, eleven days after flow from the more open area of site 6 had been observed and after the snowpack had ripened. The effect of shading by the deciduous vegetation, created a different runoff pattern that was discussed in chapter four. The duration of flow at this site was 40 days, the same length of time as for site 6, but longer than the flow duration for either site 5 or site 11. The melting of the snowpack at this site occurred at a much slower rate and small daily volumes resulted. This was partly due to the partial shading of the snowpack by the vegetation, the presence of organic material and other factors. The effect of shading by the wooded area was a factor in controlling the timing of peak daily discharge. The air in the upper levels was heated as in site 5, and not much melting resulted from direct radiation. Melting was again dependent upon the temperature of the air in the wooded area. Thus a lag in flow occurred due to a lag pattern in the heating of the air in the lower levels. As in sites 5 and 11, the porous organic material absorbed and retained much of the meltwater and discharges were small.

The site had the lowest peak discharge of any site investigated. Peak flow occurred on April 25, much later than in any of the other sites. This late peak was partly attributable to a late April snowstorm

that brought approximately 6.3 inches of fresh wet snow. The meltwater of this snowstorm became available when flow from winter snows was still high and storage capacities were fully utilized. Thus most of this additional moisture became surface runoff. Although the flow from the site ceased on May 9, there were still isolated patches of snow in the area.

The plant cover of the previously discussed sites and others of this study is important. This factor controls to a large extent the amount of moisture storage by its effect on the rate of evaporation and its creation of organic material. Also because roots, especially tree roots, withdraw moisture from greater depths of soil and there is greater recharge before surface runoff may take place.

STORAGE CAPACITY OF SURFICIAL MATERIAL

Surficial material, whether natural organic material or man-made, is another factor causing variation in meltwater runoff in the basin. The type of material and its degree of saturation, prior to freeze-up, influences the amount of infiltration and storage in the spring.

Exposed paved surfaces of the airport and roads are expected to have the lowest storage capacity and to produce the greatest percentage of runoff. This was observed especially in sites 8 and 10. Storage at these locations (pavement) was small. Even when evaporation is taken into account, losses would still be small in comparison to total yield from these sites. The factors responsible for the runoff patterns at these sites will be examined in the section on paved surfaces.

Sites covered by summerfallow fields have a greater storage

capacity than paved areas. Such areas, including sites 1, 4, 7, and 12 produced variable amounts of runoff (Table 5), more than the forested sites, but less than the paved areas. The dark colour of the exposed soil affects snowmelt patterns due to their low albedo. The factors that influence the melt patterns of these sites are discussed in the section on management practices.

The wooded areas (sites 5, 11, and 13) contain shallow accumulations of organic material which store a large volume of water. The annual storage capacity is considerable because of withdrawal of moisture by vegetation and losses to evaporation. Substantial runoff from such areas was measured during this study. The relatively small contribution of runoff from sites 5, 11 and 13 is explainable in terms of lack of saturation prior to freeze-up the previous autumn. Precipitation during September and October 1971 was 1.21 and 0.12 inches, that is, 0.15 and 0.64 inch respectively, less than the mean for each month. This does not account for complete recharge of the organic material (assuming a four inch moisture storage). Consequently, as the snowmelt period begins, such areas absorb much moisture to bring them to saturation and any residual amounts of water then go towards surface runoff.

The wooded areas receive very significant amounts of water from surrounding areas and the storage of this water greatly exceeds an average of four inches. When the amount of runoff from open areas (according to average values for such areas from Table 5 is considered), this amounts to approximately 2.12 inches. This meltwater runoff flows towards forest depressional areas, such as in sites 5 and 11. There it is utilized in large parts by the forest areas.

One site where ponded water contributed towards a distinct runoff pattern is site 14. This is a large area of approximately 956.8 acres in a variety of land uses (Table 4). It also contains a large slough (8% of the total area) that influenced the meltwater pattern from this site. This depression acts as an internal storage basin for meltwaters derived from the surrounding area. Some water remains in this depression throughout the summer, autumn and winter. During the summer and autumn some water is lost by evaporation, infiltration and by other means.

The first runoff was observed at the weir site on March 31. Runoff had occurred from the surrounding area much earlier, from March 21 onwards. This meltwater from upland areas flowed towards the lower parts of the depression. There it was stored and detained until such a time (March 31) when sufficient amounts of water had collected to start flow at the outlet end. Runoff was further delayed by a dense and compacted drift across the outlet channel. Both the approach and the outlet channels at the weir site had to be cleared so the water could flow freely and easily. The sudden rise in volume on April 10 caused the weir to be washed out. At the same time flow observations were transferred to a 36 inch culvert one mile downstream on the same channel. The delay in the start of runoff and the sudden rise in discharge on April 10 can be attributed to a number of factors including the presence of the slough, a large accumulation of snow, weather and other conditions.

Peak flow from the site was observed on April 22. The sudden rise in discharge was attributed to a late April snowstorm which brought additional amounts of snow. At that time most of the soils had been recharged sufficiently and were near saturation. The sudden addition of

more moisture could not be completely absorbed, thus much of this additional water ended up as surface runoff.

If the late April snowfall of approximately 6.3 inches has 0.63 inch of water equivalent (assuming 1 inch of water equals 10 inches of snow) and this amount multiplied by the area equals 0.325 inch, then approximately 25 per cent of this amount has run off in supplement to the hydrograph curve.

MANAGEMENT PRACTICES

Sub-basins 1, 4, 7 and 12 were selected in part because they have representative land management practices. The following descriptions of the sites deal with the land conditions at each site and the factors contributing to the variable runoff patterns.

Site 1

This site has 264.1 acres, of which approximately 61 per cent of it existed in summerfallow bare fields (Table 4). The runoff pattern in summary was more flashy than that from a wooded area, a higher yield was recorded (Table 5) and the daily variations in flow corresponded closely to the fluctuating temperatures. The bare summerfallow soils have a low albedo and this had a considerable effect on snowmelt runoff. The soils absorbed some solar energy and through absorbed heat, caused quicker melting of snow.

Some moisture was lost by infiltration and evaporation. The remaining amount (2.47 inches) was observed as runoff. This volume was considerably higher than that for the wooded areas, (sites 5, 11 and 13) but less than that for the pasture area (site 6) and the paved areas (sites 8 and 10). Once bare patches of soil were exposed, the melting

increased in the immediately adjacent areas. This factor contributed to slightly greater discharge being observed at the outlet early in the snowmelt period and also earlier drying of some surfaces. With prevailing milder weather towards the end of the snowmelt period, moisture infiltration into the soil increased and evaporation losses also increased. Subsequently the flow gradually decreased to zero on April 20. Further flow was observed for nine days starting on April 21. It was minor because the greater part of the fresh snowfall (70%) passed into soil moisture storage and evaporated upon melting.

Site 4

This site had stubble and hay fields and other uses totalling 113 acres (Table 4). The amount of runoff yielded by this site came to 1.95 inches. This amount was considerably higher than that for the wooded sites (5, 11, and 13) of this study, but less than the volumes for the summerfallow fields and paved surfaces. The increased permeability of the soil due to the presence of rooting channels influenced the moderate amount of runoff that was observed from this site. Additional moisture was lost by evaporation. The further addition of more moisture from the late April snowstorm did not affect this site in increasing the discharge from it. Most of this additional moisture infiltrated into the soil and also evaporated.

As in site 1, approximately 70 per cent of the 0.63 inch of fresh snow on April 21 passed into soil moisture and evaporated on melting. Only approximately 30 per cent remained for surface runoff. This site as well as the others in this section tend to indicate that early drying is significant in reducing total snowmelt runoff.

Site 7

This site once again is representative of land use in the basin (Table 4). The area of 261.7 acres includes approximately 163.2 acres, (62%) which were in a summerfallow state at the time of this study. The presence of this large area of bare fallow fields affected the runoff from this site. The low albedo of the dark soil contributed to slightly earlier and quicker melting of the snowpack, greater infiltration and increased evaporation losses.

The first runoff was observed on April 3, but runoff had likely started at this site much earlier, on March 21. Much of the earlier runoff went into temporary detention storage in the deeply drifted snow near the outlet of the site. Any initial discharges which may have taken place at the culverts were missed due to the difficulty in locating the culverts. The site yielded the fourth highest amount of runoff (2.81 inches). This relatively high yield can be attributed to a number of factors including pre-freeze-up moisture conditions, amount of infiltration in the spring and others. The soil of the site had absorbed some moisture in the autumn, but in the spring it was able to absorb more limited moisture. Evaporation also accounted for some additional losses. Once the soil was sufficiently recharged the residual amounts went towards surface runoff. The late April snowstorm did not have a significant effect in increasing the discharge from this plot. Most of this moisture infiltrated into the soil and evaporated on melting.

Site 9

This site occupies 67.2 acres of primarily bare summerfallow fields. This is one plot where a close relationship between the bare

fields and the resultant runoff patterns could have been formulated. The weir was insufficient for gauging the discharge from this site and only a limited part of the runoff was recorded. The first runoff was observed on March 18. On March 31 a sudden surge of water flowed through the weir. The weir notch was of insufficient size to pass the large volume of water and the structure was washed out. The one factor that was most important in causing this large flow at that time was the warm weather. Another factor that contributed to this quick rise in flow is the low albedo of the dark soil. Some solar radiation passed through the snow cover, warmed up the soil and caused additional melting at ground/snow level. Observations were continued at the site but no flow records were taken. Flow ceased at the site on April 26.

Site 12

This area consists of 347.2 acres of variable land use (Table 4). The most significant factor that contributed towards the resultant runoff pattern from this site is the presence of a shallow marshy area south and west of the inlet of the culvert. The soil of the area was moist but was not completely recharged before freeze-up. Some additional recharge from snow meltwater was thus possible in the spring. Additional moisture was lost by evaporation. The end result was that 1.13 inches of runoff were observed from this site.

A late rise in discharge was also observed at this site partly due to the snowstorm of April 21. The soil of the site was still capable of absorbing additional amounts of moisture, approximately 70 per cent of the fresh snow and leaving 30 per cent for surface runoff. Thus only minor flow, on the average of 0.017 inch, were observed

between April 24 and April 29 (Figure 14C). Runoff from the site stopped on May 4.

PAVED SURFACES

Areas such as the paved runways and other parts of the Edmonton International Airport, all-weather roads, urban developments and other related land uses produce distinct runoff patterns completely different than those from agricultural and natural vegetation areas. Such land use types tend to have limited infiltration, soil moisture storage and evapotranspiration, and increased runoff. Infiltration can range from zero on pavement and other similar areas to values exceeding precipitation and snowmelt rates. Two representative plots in this study (sites 8 and 10) illustrate the variable flow patterns that result primarily from runoff from paved areas of the airport.

Site 8

This site covering approximately 755.2 acres of compound land use (Table 4) yielded 2.92 inches of runoff, the third highest volume after sites 10 and 6. The two categories of pavement and turf cover approximately 37 per cent of the total area. This area is of considerable importance in runoff yield and regime patterns. The paved surfaces have low albedo which caused early melt due in part to snow clearing which exposed dark surfaces very early in the snowmelt period and contributed to early melting. Runoff began at the gauge on March 20, five days later than from site 10. Snowmelt runoff from runways started here just as early as in site 10. In this site detention storage between the runways and the gauge was probably significant and this likely contributed to a lag in flow at the outlet. The paved areas

have an extremely low permeability and this results in practically no infiltration and moisture storage, but does result in flashier flows and larger discharge volumes than from all other sites except site 10.

The exposed and open paved areas absorb much solar radiation. The amount of sun was probably important. The low albedo of the dark surfaces combined with the warm weather conditions contributed to increased melting and a larger flow being recorded at the outlet of this plot. Such discharge periods were noted, for example, from March 20 to March 24, March 29 to April 1 and April 5 and 6 (Figure 14B). When cooler temperatures returned, melting was restricted and runoff decreased in response to the conditions. The runoff from the site increased relatively quickly, at times when more precipitation fell, for example, on April 15 and again between April 23 and April 28. The factor that contributed towards these increases is the impermeable nature of the paved areas. Most of the additional moisture remained on the surface. The system of drains quickly conducted the water towards the natural drainage channels and the culverts at the outlet of the plot. Runoff ceased on May 11, after a flow duration of 52 days.

Site 10

This site also occupies a similar land use area as site 8, (Table 4), but the flow pattern from it was distinctly different than that from any other site. The plot encloses approximately 414.4 acres of which 34 per cent consists of paved areas and 28 per cent of turf area. This large portion of impermeable area, combined with the many surface and subsurface drains, contribute to flashy runoff as in site 8.

Runoff started very early from this site, on March 15. This early beginning was attributable to the impermeability of the paved

area, the low albedo of the pavement causing quick melting of the snowpack, the prevailing weather conditions and the drainage system of the airport. Runoff from this site lasted for 61 days, the longest flow duration of any site of this study. During that time 7.15 inches of runoff were recorded. Peak flow was observed on March 20 just five days after runoff had started. Sudden, flashy increases in runoff, from additional moisture and also from days when melting was rapid due to mild temperatures, were observed for this site as they were for site 8. A flashy flow and a large amount of runoff which was anticipated was observed, but the 7.15 inches were actually greater than the amount of precipitation (6.74 inches). Possible reasons for this error were given in chapter four. The long flow duration can be attributed to the drainage system of the airport combined with the weather conditions. Any of the moisture which percolated into the soil in the turf area was eventually collected by the complex system of perforated drainage pipes beneath the runways and directed towards the natural drainageways. In this way when the paved areas and surrounding fields were devoid of snow, there was still considerable runoff through the culvert. The slow percolation of moisture to the drainage pipes is a factor for the runoff period being prolonged at this site.

CHAPTER VI

SUMMARY AND CONCLUSIONS

In chapter five, several of the environmental factors that cause variable snowmelt runoff patterns in the basin were discussed. It was shown that these factors are significant and closely related to the runoff patterns. This final chapter is a summary of some of the more significant findings of this study. Some practical applications of this study are also indicated.

SUMMARY

In this preliminary study, snowmelt runoff patterns from fourteen representative sites within the Whitemud Creek Basin were examined. In chapter one it was shown just how important man is as an agent in altering the hydrology of areas in various parts of the world. The reasons for choosing this area and topic were stated and the scope and purpose of the study were discussed. In addition to the above, the methodology and approach were reviewed.

In chapter two, the physical features of the basin were examined. It was indicated how the basin's physiographic, hydrologic and climatic characteristics may affect the local surface runoff patterns. The annual average precipitation of 17.67 inches, depending largely upon seasonal distribution patterns, is sufficient to produce runoff in most

years. The greater part of the surplus can be attributed to snowmelt runoff. This was brought out in the section on hydrologic characteristics in chapter two. This is also evident in the water balance calculations using the Thornthwaite method (Appendix A). In the second chapter it was also suggested how and why the main creek should have variable seasonal discharge patterns. Many of these anticipated patterns were found to be present and were discussed in later chapters. Further evaluation and confirmation or denial of the findings of this study however, require additional studies based on longer records of observation.

In the third chapter the effects of changing land use in the basin were discussed. The conditions prevalent in the basin were examined with reference to pre-settlement, effects of settlement and present state of the land. A number of preliminary assumptions of expected surplus patterns were made. Reference was made to land use changes and how such alterations influence the runoff patterns.

In chapter four some theoretical aspects of snowmelt were considered and these were applied to the physical conditions in the Whitemud Creek Basin. The snowmelt runoff patterns for the fourteen representative sites were described. In addition preliminary observations for meltwater quality were also presented.

The factors that cause variation in snowmelt runoff were then reviewed and evaluated in chapter five of this study.

SOME PRACTICAL IMPLICATIONS OF THE STUDY

The preliminary results of this study indicate a surplus of flow from all sample plots (Table 5). The total volume, duration of flow and timing of discharge varied considerably from one site to the other.

The resultant runoff patterns were found to be dependent upon the complex interaction of a number of physical and climatic factors. Some physical elements important to snowmelt runoff are extent of exposed bare soil and pavement, type and thickness of surficial material, moisture storage at freeze-up, differences in vegetation cover and land use. Some significant climatic factors include weather events before freeze-up, patterns of winter snow accumulation, and weather conditions during the spring snowmelt period. The following conclusions are preliminary ones and to substantiate these further studies are desirable.

Paved surfaces (airport runways) due to their impermeability, very low storage capacity, complex system of drains and low albedo, were found to have the greatest volume of runoff, the flashiest flow and also a more sustained flow. Most of the precipitation that fell on these surfaces went to surface runoff. The yield of runoff from the airport area is partially dependent upon the proportional area under pavement.

Cultivated forage crops and improved pastures tended to have the next largest runoff (3.89 inches) and a long flow duration (41 days). This may be attributable to the more compacted soils, and lesser infiltration, thus large amounts of runoff resulted. Some of the areas may have high infiltration capacities, but many have low capacities because of grazing intensities and compaction of surfaces. The flow was not as flashy as from paved areas and cropland areas.

The summerfallow and stubble fields, having an earlier or a more prolonged period of melting and a longer term of infiltration than the previous land use types, produced the next lowest runoff (on the average about 2.12 inches). The flow from these cropland areas was

relatively flashy and flow duration averaged out to 40 days. The low albedo of the dark soils contributed significantly to the resultant flow pattern. It influenced early melting of snow in these areas and once dark soil surfaces were exposed, this resulted in quicker melting and flashy runoff especially when bright sunny conditions persisted. In some areas runoff was prolonged due to drifts restricting the flow and also ponding.

The areas which yielded the lowest amount of meltwater (on the average of 0.13 inch), over a flow duration of approximately 35 days, were the forested plots of the basin. Much of this yield was derived from non-forested parts (open fields) of the sub-basins which in fact supplied extra moisture for use by and in the non-productive woodplots. These areas have much lower peak flows and also the lowest daily discharges of all the areas studied. This flow pattern can be attributable to the presence of surficial organic material in these depressional forested areas, which absorbs much moisture from within the plots and from adjacent surrounding areas. This moisture is retained in storage for later use. The daily peak flows from these wooded areas also occurred much later than in all the other sites. This pattern in flow very likely resulted from a lag in melting, which in turn was due to a lag in warming of air in the lower levels of the forested sites. The effect of shading by the vegetation at these sites contributed to slower melting of the snow and consequently to lower daily runoff volumes. In these protected areas, patches of snow remain the longest.

The weather conditions before freeze-up, in the autumn of 1971, were such that about 1.21 and 0.12 inches of precipitation fell during September and October respectively. This amount was insufficient to

recharge soils to a four inch storage level. According to the Thornthwaite water balance procedure, there were approximately 2.12 inches in soil moisture storage and snow detention storage (assuming a 4 inch storage capacity) at the end of 1971. Thus most areas in the basin were capable of absorbing additional amounts of moisture in the spring. This was indicated from the results of this study. Thus the amount of water held in storage by surficial material at the time of fall freeze-up exerts some control over the volume of moisture uptake during the following spring.

Considerable drifting of snow resulted during the winter and deep accumulations develop in some areas. These contribute considerable amounts of moisture to areas. Areas that lose snow by drifting may have little or no moisture for runoff after soil moisture storage is recharged. In contrast, drift areas often have significant surpluses. Thick snowdrifts were noted along the northern edges of the forested sites, where they provided moisture for the sites and also for runoff.

The weather conditions during the spring, especially daily air temperature and the intensity of solar radiation directly influence the rate of snowmelt. This relationship was observed this year, for example, on March 30 and March 31 when mild temperatures prevailed, sudden increases in discharge were observed from most sites. This is also well illustrated on the snowmelt hydrographs (Figures 14A, 14B, 14C). Once cooler temperatures returned the flows also decreased, due to less melt contributions and also the restricting of flow by ice and snow.

Topographic variation within the Whitemud Creek Basin is not great and only slightly influences the spring snowmelt patterns. The limited relief in the sub-basins results in only minor aspect differences.

Due to the limited relief, the effect of both aspect and slope was apparently minor, but they do modify the runoff pattern slightly on a local scale.

Generally, Whitemud Creek has a variable seasonal flow pattern that is determined to a large extent by the climatic conditions in the area. There are no flows recorded during the months from September through to the middle of March. From approximately the end of March to the middle of April, the discharge rapidly peaks. After the snowmelt runoff period low flows are recorded again, only to be interrupted by occasional extended periods of summer rains.

Although some of these conclusions are preliminary and should be confirmed by longer periods of study, some practical applications of this information are possible.

In this study, the Thornthwaite bookkeeping procedure was employed and it was found to be reasonably suitable for water balance calculations for the Edmonton region. Relatively close agreements exist between runoff values calculated by this procedure and the actual observed values. A longer period of observation for comparison purposes is desirable and to confirm or deny the results might be useful research at some later date. It may thus provide useful guidelines for estimating surpluses, not only for the Edmonton region but also for other regions of the Prairie Provinces where runoff data and discharge records are not available.

The moisture patterns based on the 2, 4 and 6 inch storage capacities are confirmed by the contrasts in runoff for different land use types in the area this year. However, in order to substantiate the findings of the present study, additional observations in other years,

especially some very dry and also very wet years would be desirable.

The study also indicated that many of the vegetation patterns present in the basin, in the past and today, are complementary to each other and are closely related to water balance patterns. The wooded areas probably have relatively small deficits because of their use of wind-drifted snow in addition to meltwater from adjoining areas. The improved pastures and areas of forage crops have some runoff and snow loss by drifting. These areas consequently tend to have larger moisture deficits, which account in large degree for them continuing to be pasture lands.

It is also implied that land management practices could be improved to enhance infiltration and surface detention storage. Such methods as stubble mulch tillage and various other means of leaving rougher land surfaces in the fall within sub-basins of the area, may be beneficial and could result in greater soil moisture retention storage for later crop use. In addition, it has been shown that the practice of summer fallowing does result in an earlier and larger runoff and may not result in much, if any, increased soil moisture storage.

Certain surfaces in the basin including improved pastures, pavements and some croplands, will have runoff in most winters. In such areas infiltration capacities are low or major drift accumulation may be present and thus there is a good potential for the development of dugouts, stockwatering dams, and other water supplies in the area.

The major and flashy surpluses in the basin come from the airport area, roadside ditches, and summerfallow fields. At the outlets of culverts from some areas there are deep scour holes and problems of erosion were also evident in fields in the form of deep gullies. These

areas that produce this high runoff tend to give rise to such problems as sediment erosion from fields, possibly flooding and water quality depreciation.

It was also pointed out that if wooded areas are cleared and depressions are drained by ditching, much moisture is lost and flashy runoff conditions may develop, which in turn may give rise to greater erosion along the flow path.

The findings of this study could also provide an initial basis for culvert design, in that origins of different flows were indicated. Thus the information presented in the study could be useful for the determination of culvert sizes, their location and other necessary design features.

In conclusion, several objectives which have been met were presented:

1) The examination of land use changes within the Whitemud Creek Basin as a means for establishing relationships between the effects of these upon their local runoff characteristics. In the study, some of the changes in land use that have occurred in the basin were examined. The 2, 4, and 6 inch storage based runoff averages for the 89 year period were tentatively applied to the areas where changes in use occurred. The average annual storage based surpluses (2.89, 1.29, and 0.62 inches) for the 89 year period are composite values of both snowmelt and rainfall runoff. The order of difference in these values appears to be realistic, in that similar differences in runoff were observed from different land use areas in the basin.

It is thus probable that the hydrologic regime of the basin has progressed gradually from one where slow, evenly distributed flows

occurred, to one where much more erratic flow conditions exist as a result of man's changes in land use. Man's changes in the environment are significant and important, but the variable climate is still a more important factor in influencing the runoff patterns.

The main result of man's development of the land in the basin has been a general decline in woodland area in the natural landscape, thus altering the water balance patterns. Snow removal and accumulation by wind is more pronounced, spring snowmelt is accelerated, and runoff from most areas is more rapid. Additional research is needed if these preliminary conclusions are to be more firmly established.

2) The observation of the effects of some existing land uses in the basin on runoff patterns, in order to provide a comparative reference point for future measurements following further alterations in use. From preliminary results of this study, the variable snowmelt runoff patterns in the basin are closely related to land use. Land use, whether for cultivation, pasture, forest or urban purposes, exerts an important influence on the rate and timing of snowmelt and hence on runoff from snowmelt. In order to judge their quantitative significance and the extent of their applicability, additional research into land use areas and runoff might be useful.

3) The collection of water samples for chemical analyses from representative sites so that qualities of surface runoff water may be assessed and related to various environmental conditions. Only very preliminary conclusions, with respect to quality of runoff waters from different land use areas, were derived and additional research into this area is desirable. For example, a sediment study might be undertaken to determine which areas contribute the largest amounts of sediment in the basin and why.

4) The testing of methods and techniques for observations. Both gauging devices (weirs and culverts) provided reasonably reliable results. The use of other culverts in the area to verify some results of this study might be useful. A possible better method of measuring runoff using the culverts or other devices may also be desirable.

These objectives then could be bases for separate more detailed topics. If these are pursued they will contribute to a more complete and better understanding of the basin's physical and hydrological characteristics, land use patterns and climate.

BIBLIOGRAPHY

General Sources

Allan, J. A. Geology of Alberta Soils. Edmonton: Research Council of Alberta, Report No. 34, Part III, 1943, pp. 60-146.

American Society of Civil Engineers, Committee on Hydrology. Hydrology Handbook. A. S. C. E., 1957, 184 pp.

American Water Works Association, Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater. N. Y.: American Public Health Association, Inc., 1965, 769 pp.

Antoniuk, S. A. A mineralogic study of the Saskatchewan gravels and sands. Unpublished M. Sc. Thesis, Dept. of Geology, University of Alberta, Edmonton, 1954, 61 pp.

Bayrock, L. A., and G. M. Hughes. Surficial Geology of the Edmonton District, Alberta. Edmonton: Research Council of Alberta, Preliminary Report 62-6, 1962, 40 pp.

______________, and T. E. Berg. Geology of the city of Edmonton, Part I: Central Edmonton. Research Council of Alberta, Report,66-1, 1966, 30 pp.

Bird, C. D., and R. D. Bird. The Aspen Parkland. Chapter seven in Alberta, A Natural History. Edmonton: M. G. Hurtig, 1967, pp. 135-144.

Bouthillier, P. H., and H. L. Hogge. "Stream Pollution and its Control in Alberta". Engineering Journal, Vol. 43, No. 6, June 1960, pp. 56-64.

Bowser, W. E. et. al. Soil Survey of the Edmonton Sheet. Edmonton: University of Alberta, Alberta Soil Survey Report No. 21, 1962, 66 pp.

Canada Department of Interior. Description of Townships of North West Territories, Dominion of Canada, West of the Fourth and Fifth Initial Meridians. Ottawa: McLean, Roge and Co., 1886, 386 pp.

Canadian National Committee. Snowmelt Hydrology. Ottawa: I.H.D. Secretariat, Proceedings of a Workshop Seminar held in Frederiction, N.B., 1968, 82 pp.

Carlson, V. A. Bedrock Topography and Surficial Aquifers of the Edmonton District. Edmonton: Research Council of Alberta, Report 66-3, 1967, 21 pp.

Cashman, A. W. The Edmonton Story. Edmonton: Institute of Applied Art, 1956, 123 pp.

Chorley, R. J. (ed.) Water, Earth and Man, a synthesis of Hydrology, Geomorphology and Socio-economic Geography. London: Methuen and Co. Ltd., 1969, 588 pp.

Chow, Ven Te. (ed.) Handbook of Applied Hydrology. N.Y.: McGraw Hill Book Co. Inc., 1964, 1,418 pp.

Clark, R. H. "Canada's Surface Water Resources". Engineering Journal, Oct. 1968, pp. 8-18.

Cram. J.S. Water, Canadian needs and resources. Montreal: Harvest House Ltd., 1968, 184 pp.

Duff, D.E. Some analyses of Pleistocene deposits in the Edmonton area. Unpublished M.Sc. Thesis, Dept. of Geology, University of Alberta, Edmonton, 1951, 47 pp.

Edmonton Planning Commission. General Plan for the City of Edmonton. Edmonton: 1967, 170 pp.

Farvolden, R.N. Bedrock topography; Edmonton-Red Deer Map-area, Alberta. In early contributions to the groundwater hydrology of Alberta, R. N. Farvolden, et. al., Research Council of Alberta, Bull., No. 12, pp 57-62.

Gravenor, C.P., and L.A. Bayrock. Glacial deposits of Alberta. In Soils of Canada; Roy. Soc. Can. Special Publ., No. 3, 1961, pp. 33-50.

Gray, D.M. (ed.) Handbook on the Principles of Hydrology, National Research Council. Ottawa: Secretariat, Canadian National Committee for the I.H.D., 1970.

Hardy, W.G. (ed.) The Alberta Golden Jubilee Anthology. Edmonton: McClelland and Steward Ltd., 1955, 471 pp.

___________,(ed.) Alberta,A Natural History. Edmonton: M.G. Hurtig, 1967, 343 pp.

Kazmann, R.G. Modern Hydrology. N.Y.: Harper and Row, 1965, 301 pp.

Keeble, A.B. "The mode of Origin and Depositional History of Kames, S.W. of Edmonton". The Albertan Geographer, No. 6, 1970, pp.33-44.

Klein, L. Aspects of River Pollution. London: Butterworths Scientific Publications, 1957, 621 pp.

________. River Pollution: Causes and Effects. London: Butterworths Scientific Publications, 1962, 456 pp.

Kneese, A.V., and S.S. Smith. Water Research. Baltimore: John Hopkins Press, 1967, 362 pp.

La Roi, G.H. The Boreal Forest; Taiga. Chapter eight in Alberta, A Natural History. Edmonton: M.G. Hurtig, 1967, pp. 151-169.

Laycock, A.H. "Local Water Supplies in the Prairies". Paper presented at annual convention of the C.A.G., Saskatoon, Sask., May 1959. Mimeo, 12 pp.

Le Breton, E.G. Groundwater Geology and Hydrology of East-Central Alberta. Research Council of Alberta, Bull. 13, 1963, 64 pp.

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. Applied Hydrology. N.Y.: McGraw Hill Book Co.Inc., 1949, 689 pp.

________. Hydrology for Engineers. N.Y.: McGraw Hill Book Co.Inc., 1958, 340 pp.

Luthin, J.N. Drainage Engineering. N.Y.: John Wiley and Sons, Inc., 1966, 250 pp.

Moodie, D.W. The St. Albert Settlement: A Study in Historical Geography. Unpublished M.A. Thesis, Dept. of Geogr., University of Alberta, Edmonton, 1965, 179 pp.

Moss, E.H. "The Vegetation of Alberta". The Botanical Review. Vol. XXI, 1955, pp. 493-567.

National Research Council of Canada. Proceedings of Hydrology Symposium No. 1, Spillway Design Floods. Ottawa: Queen's Printer, 1959, 304 pp.

________. Proceedings of Hydrology Symposium No. 3, Groundwater. Ottawa: Queen's Printer, 1962, 394 pp.

________. Proceedings of Hydrology Symposium No. 4, Research Watersheds. Ottawa: Queen's Printer 1964, 321 pp.

________. Proceedings of Hydrology Symposium No. 6, Soil Moisture. Ottawa: Queen's Printer, 1967, 336 pp.

Ockley, B.A. A history of early Edmonton. Unpublished M.A. Thesis, Dept. of History, University of Alberta, Edmonton, 1932, 365 pp.

Ower, J.R. The Edmonton Formation. Edmonton Geol.Soc.Quart.,1958, Vol.2, No. 1, pp. 3-11.

Palliser, J. Exploration - British North America. London: Eyre and Spottiswoode, for H.M. Stationery Office, 1863.

Rains, R.B. Some Aspects of the Fluvial Geomorphology of the Whitemud Basin, Central Alberta. Unpublished Ph.D. Thesis, Dept. of Geogr., University of Alberta, Edmonton, 1969, 227 pp.

__________. "Differentiation of till deposits in the Whitemud Creek valley, Edmonton, Alberta". The Albertan Geographer, No. 5, 1969, pp. 12-20.

Russel, B.E. "The water resources of Alberta". The Engineering Journal, Vol. 31, No. 9, 1948, pp. 476-483.

Rutherford, R.L. "Two interesting boulders in the glacial deposits of Alberta", J. Geol., Vol. 36, 1928, pp. 558-560.

Toebes, C., and V. Ouryvaev (eds.) Representative and Experimental Basins. A contribution to the I.H.D., Unesco, 1970, 348 pp.

Toogood, J.A. "Water erosion in Alberta", Soil and Water Conservation, Vol. 18, 1963, pp. 238-240.

__________., and J.D. Newton. Water Erosion in Alberta. Edmonton: U. of Alta., Faculty of Agriculture, Bull. No. 56, 1955, 39 pp.

Tyrrell, J.B. Report on a part of Northern Alberta and portions of adjacent districts Assiniboia and Saskatchewan, G.S.C. Ann.Report, Vol. 2, Pt. E., 1886, pp. 1-176.

Ward, R.C. Principles of Hydrology. London: Mcgraw Hill Publ. Co. Ltd., 1967, 403 pp.

Webb, R., A. Johnston, and J.D. Soper. The Prairie World. Chapter five in Alberta, A Natural History. Edmonton: M.G. Hurtig, 1967, pp. 93-115.

Whelan, D.E. "A method of evaluating the hydrologic effects of land use on large watersheds". Trans., A.G.U., Vol. 31, No. 2, April 1950, pp. 253-261.

Williams, W.H. Manitoba and the North-West; Journal of a Trip from Toronto to the Rocky Mountains. Toronto: Hunter, Rose and Co., 1882, 258 pp.

Wilson, E.M. Engineering Hydrology. London: Macmillan and Co. Ltd., 1970, 182 pp.

Climate and Water Balance

American Society of Agricultural Engineers. Conference Proceedings: Evapotranspiration and its role in water resources management. Conf. Proc. Am. Soc. Agric. Engin., Dec. 1966.

Baier, W. "The interrelationships of meteorological factors, soil moisture and plant growth", in Water and Climate, a Symposium. Saskatoon: U. of Sask., Water Studies Institute, Report No. 2, 1965, 20 pp.

________. "Studies on estimating potential evapotranspiration from empirical relationships". South African Journal of Agricultural Science, Vol. 6. No. 3, 1963, 455-474 pp.

Blaney, H.F. "Definitions, methods and research data. A symposium on the consumptive use of water". Trans. Am. Soc. Civ. Eng., Vol. 117, Paper 2524, 1952, 949-967 pp.

___________., and W.D. Criddle. "Determining consumptive use and irrigation requirements". U.S.D.A., Tech. Bull. 1275, 1962, 59 pp.

Borchert, J.R. "The Climate of the Central North American Grassland". Annals of Assn. of Amer. Geogr., Vol. XL, March 1950, pp. 1-39.

Bruce, J.P., and R.W. Clark. Introduction to Hydrometeorology. London: Pergamon Press, 1966, 319 pp.

Chang, J.H. "On the study of evapotranspiration and water balance". Erdkunde, Vol. 19, 1965, pp. 141-150.

Cole, D.W., and P.S. Machno. "Factors Affecting Percolation in a Forest Soil". In A.W.R.A. Symposium on Water Balance in North America, Proceedings Series No. 7, 1969, pp. 101-109.

Connor, A.J. Temperature and Precipitation of Alberta, Saskatchewan and Manitoba. Toronto: Department of Transport, 1920, 170 pp.

Gray, D.M. "Climate and Water", in Water and Climate, a Symposium. Saskatoon: Univ. of Sask., Water Studies Institute Report No.2, 1965, pp. 46-66.

Hursh, C.R., M.D. Hoover, and P.W. Fletcher. "Studies in the balanced water economy of experimental drainage areas". Trans. A.G.U., Vol. 23, 1942, pp. 509-516.

Kakela, P.J. Snow and the Thornthwaite Water Balance In a Subarctic Environment. Unpublished Ph.D. Thesis, Dept. of Geogr. U. of Alberta, Edmonton, 1969, 289 pp.

Kendrew, W.G., and B.W. Currie. The Climate of Central Canada. Ottawa: Queen's Printer, 1955, 194 pp.

Laycock, A.H. Water Deficiency and Surplus Patterns in the Prairie Provinces. Regina: Prairie Provinces Water Board Report 13, 1967, 92 pp., maps.

__________. "Geographic Aspects of Water and Climate", in Water and Climate, a Symposium. Saskatoon: Univ. of Sask., Water Studies Institute Report No. 2, 1965, pp. 1-20.

__________. "Summer fallowing as a means of moisture conservation in the Prairie Provinces". Paper presented at annual meeting of the C.A.G., Montreal, P.Q., June, 1961. Mimeo, 10 pp.

__________., M. Francisco and T. Fisher (eds.). Water Balance in North America. Urbana: A.W.R.A. Proceedings Series 7, held at Banff, Alta., June, 1969, 335 pp.

Longley, R.W. "Climate and Weather Patterns", Chapter three in Alberta, A Natural History. Edmonton: M.G. Hurtig, 1967, pp. 53-67.

Mather, J.R. "The climatic water balance". Publications in Climatology, Vol. XIV, No. 3. Centerton: Lab. of Climatology, Centerton, N.J., 1961, pp. 249-264.

__________. (ed.). "The measurement of Potential Evapotranspiration". Publications in Climatology, Vol. VII, No. 1. Centerton: Lab. of Climatology, Centerton, N.J., 1954, 225 pp.

__________. "The moisture balance in grassland climatology", in American Assoc. for the Advancement of Science, Grasslands; a Symposium. Washington: A.A.A.S., 1959, pp. 251-261.

__________. "Determination of evapotranspiration by empirical methods". Trans. Am. Soc. Agric. Eng., Vol. 2, No. 1, 1959, pp. 35-38, 43.

Meteorological Branch, Ministry of Transport, Canada. 1970 Annual Meteorological Summary with comparative data and long term records. Edmonton: Weather Office, International Airport, 1971, 32pp.

Mustonen, S.E., and J.L. McGuinness. "Estimating evapotranspiration in a humid region". U.S.D.A.Tech. Bull. 1389, 1968,123 pp.

Muttitt, G.H. "Spring and Summer Rainfall Patterns in Alberta". Ottawa: Canada Dept. of Transport, Met. Br.,CIR-3512, TEC-361, 1961, 22 pp.

National Research Council of Canada. Proceedings of Hydrology Symposium No. 2, Evaporation. Ottawa: Queen's Printer, 1961, 263 pp.

Pelton, W.L., and H.C. Korven. "Evapotranspiration estimates in a semi-arid climate". Canadian Agricultural Engineering, Vol.11, No. 2, 1969, pp. 50-53,61.

Penman, H.L. "Weather, plant, and soil factors in hydrology". Weather, Vol. 16, No. 7, 1961, pp. 207-219.

__________. "Natural evaporation from open water, bare soil and grass". Royal Society of London Proceedings, A 193, 1948, pp. 120-146.

__________. "Evaporation: An introductory survey". Netherland Journal of Agricultural Science, Vol. 4, 1956, pp. 9-29.

Potter, J.G. "Snow Cover". Ottawa: Canada Dept. of Transport, Met. Br., Climatological Studies,No. 3, 1965, 69 pp.

Raney, W.A. "Evaluation of Evapotranspiration in Field Plots". Trans. Am. Soc. Agric. Eng., Vol. 2, No. 1, 1959, 41 pp.

Rider, N.E. "Water losses from various land surfaces". London Royal Meteorological Society, Quarterly Journal, Vol. 83, 1957, pp. 181-193.

Sharma. V.K. Evapotranspiration and water balance in the Sturgeon River Basin, Central Alberta. Unpublished M.Sc. Thesis, Dept. of Geogr., U. of Alberta, Edmonton, 1971, 105 pp.

Slaymaker, H.O., and W.W. Jeffrey. "Physiography - Land Use Interactions in Watershed Management". In A.W.R.A. Symposium on Water Balance in North America, Proceedings Series No. 7, 1969, pp. 170-181.

Taylor, C.A. "Transpiration - and evaporation losses from areas of native vegetation". Trans. A.G.U., 1934, pp. 544-559.

Thomas, M.K. "Climatic trends on Canadian Prairies", Water and Climate, a Symposium. Saskatoon: Univ. of Sask., Water Studies Institute Report No. 2, 1965, pp. 21-42.

Thornthwaite, C.W. "Contribution to Report of Committee on Transpiration and Evaporation". Trans. A.G.U., Vol. 25, Pt. 5, 1945, pp. 683-693.

______________. "The Moisture Factor in Climate". Trans. A.G.U., Vol. 27, 1946, pp. 41-48.

______________., and B. Holzman. "The determination of evaporation from land and water surfaces". Monthly Weather Review, Vol. 67, 1939, pp. 4-11.

______________. "An approach toward a rational classification of climate". Geographical Review, Vol. 38, No. 1, 1948, pp. 55-94.

_______________., and J.R. Mather. "The Water Balance". Publications in Climatology, Vol. 8, No. 1. Centerton: Lab. of Climatology, Centerton, N.J., 1955, 104 pp.

_______________. "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance". Publications in Climatology, Vol. 10, No. 3. Centerton: Lab. of Climatology, Centerton, N.J., 1957, pp. 185-311.

_______________., and D.B. Carter. Three Water Balance Maps of Eastern North America. Washington, D.C.: Resources for the Future, Inc., 1958.

U.S. Army Corps of Engineers. Snow Hydrology; Summary Report of the Snow Investigations. Portland, Oreg.: N. Pacific Div., 1956, 437 pp.

Van Wijk, W.R., and D.A. DeVries. "Evapotranspiration". Netherland Journal of Agricultural Science, No. 2, 1954, pp. 105-119.

Verma, T.R. Moisture balance in Soils of the Edmonton Area. Unpublished Ph.D. Thesis, Dept. of Soil Science, U. of Alberta, Edmonton, 1968, pp. 204.

Runoff and Streamflow

Addison, H. Hydraulic Measurements, A Manual for Engineers. N.Y.: John Wiley and Sons, 1941, 301 pp.

Betson, R.P. "What is watershed runoff?". Journal of Geophysical Research, Vol. 69, No. 8, 1964, pp. 1541-1552.

Central Snow Conference, Proceedings Vol. 1. East Lansing Michigan, Michigan State College, 1941, 214 pp.

Chebotarev, N.P. Theory of Stream runoff. Israel Program for Scientific Translations. S. Manson (printers), 1966, 464 pp.

Church, J.E. "The melting of snow", in Proceedings, Vol. 1, Central Snow Conference. East Lansing Michigan, Michigan State College, 1941, pp. 21-32.

Clark, R.H. "Predicting the runoff from snowmelt". Engineering Journal, April, 1955, pp. 434-441.

Dunne, T., and R.D. Black. "Runoff Processes during snowmelt". Water Res. Res., Vol. 7, No. 5, 1971, pp. 1160-1172.

Foster, E.E. Rainfall and Runoff. N.Y.: Macmillan, 1949, 487 pp.

Garstka, W.U., L.O. Love, B.C. Goodell, and F.A. Bertle. Factors Affecting Snowmelt and Streamflow. Washington: U.S.G.S., Publications. U.S.G.P.O., 1958, 190 pp.

Gray, D.M. "Physiographic characteristics and the runoff pattern", in Proceedings of Hydrology Symposium No. 4, Research Watersheds. Ottawa: National Research Council, Queen's Printer, 1964, pp. 147-166.

Grover, N.C., and A.W. Harrington. Stream Flow - measurements, records, and their uses. N.Y.: Dover Publications, Inc., 1966, 363 pp.

Hays, O.E. "Factors influencing runoff". Agricultural Engineer, Vol. 36, 1955, pp 732-735.

Heley, A.S. "Areal variations of mean annual runoff". J. of Hydr. Div., Proceedings A.S.C.E., Vol. 90, No. H.Y. 5, 1964, pp. 61-80.

Johnston, J.T. "Surface water supply and runoff of the prairie provinces". The Engineering Journal, Vol. 18, No. 4, 1935, pp. 181-193.

Landals, A.G. Variation in the volume of surface runoff during snowmelt period: Yellowknife, Northwest Territories. Unpublished M.Sc. Thesis, Dept. of Geogr., U. of Alberta, Edmonton, 1970, 115 pp.

Lvovitch, M.I. "Streamflow formation factors". Proceedings of the I.A.S.H., General Assembly of Toronto, Vol. 3, Publ. 45, 1957, pp. 122-132.

Mac Kay, D.K. "Characteristics of River Discharge and Runoff in Canada". Geographical Bull., Vol. 8, No. 3, 1966, pp. 219-227.

Merva, G.E., R.D. Brozee, G.O. Schwab, and R.B. Curry. "A proposed mechanics for the investigation of surface runoff from small watersheds. 1, Development". Water Res. Res., Vol. 5, No. 1, 1969, pp. 76-83.

Meyer, O.H. "Analysis of Runoff Characteristics". Trans. No. 105, Proc. A.S.C.E., Vol. 66, No. 8, Pt. 2, 1940, pp. 83-100.

Miller, S.A. "Some snow-melt runoff characteristics". Trans. A.G.U., Vol. 31, No. 5, 1950, pp 741-749.

Moore, W.L., and C.W. Morgan (eds.). Effects of Watershed Changes on Streamflow. Austin: University of Texas Press, Austin, Texas, 1969, 289 pp.

Neill, C.R., D.I. Bray, F. Shouten, and J.R. Card. Selected Characteristics of Streamflow in Alberta. Edmonton: Research Council of Alberta, River Engineering and Surface Hydrology Report 70-1, 1970, 55 pp.

Piper, A.M. "Runoff from rain and snow". Trans. A.G.U., Vol. 29, No.4, 1948, pp. 511-519.

Potter, W.D. "Peak Rates of Runoff from Small Watersheds". Washington: U.S. Bureau of Public Roads. Hydraulic Design Series No. 2, U.S.G.P.O., 1961, 35 pp.

Sanderson, M.E., and D.W. Phillips. Average Annual Water Surplus in Canada, Climate Studies No. 9. Toronto: Dept. of Transport Meteorological Branch, 1967, 76 pp.

Satterlund, D.R., and A.R. Eschner. "Land use, snow, and streamflow regimen in central New York". Water Res. Res., Vol. 1, No. 3, 1965, pp. 397-405.

Schiff, L., and F.R. Dreibelbis. "Infiltration, soil moisture, and land-use relationships with reference to surface runoff". Trans., A.G.U., Vol. 30, No. 1, 1949, pp. 75-88.

______________________________. "Movement of water within the soil and surface runoff with reference to land use and soil properties". Trans., A.G.U., Vol. 30, No. 3,1949, pp. 401-411.

Snyder, F.F. "A conception of runoff-phenomena". Trans. A.G.U., Pt. 4, 1939, pp. 725-738.

Sopper, W.E., and H.W. Lull. "Streamflow Characteristics of Physiographic Units in N.E.U.S." Water Res. Res., Vol. 1, No. 1, 1965, pp. 115-124.

Stichling, W., and S.R. Blackwell. "Drainage Areas as a Hydrologic Factor on the Glaciated Canadian Prairies". International Union of Geodesy and Geophysics, I.A.S.H., Publ. 45, Vol. 3, 1957, pp. 365-376.

Taylor, A.B., and H.E. Schwarz. "Unit hydrograph lag and peak flow related to basin characteristics". Trans., A.G.U., Vol. 33, pp. 235-246.

U.S. Army Corps of Engineers. Runoff from Snowmelt. Washington: Engineering and Design Manual EM1110-2-1406, U.S.G.P.O., 1960, 75 pp.

Viessman, W. Jr. "Runoff Estimation for Very Small Drainage Areas". Water Res. Res., Vol. 4, No. 1, 1968, pp. 87-93.

Witherspoon, D.F., and H.D. Ayers. "Measuring watershed runoff in Ontario". Agricultural Engineering, Vol. 39, 1958, pp 403-405, 411.

Work, R.A. Stream-Flow Forecasting from Snow Surveys. Washington: U.S.D.A., Circular 914, U.S.G.P.O., 1953, 16 pp.

Zoller, J.H., and A.T. Lenz. "Snowmelt runoff". J. Hydr. Div., Proc. A.S.C.E., Vol. 84, No. H.Y. 6, 1958, 31 pp.

Forest Hydrology

Beke, G.J. Alberta Watershed Soils and their Hydrologic Significance. Unpublished Ph.D. Thesis, Dept. of Soil Science, U. of Alberta, Edmonton, 1969, 456 pp.

Brown, H.E., and J.R. Thompson. "Summer Water Use by Aspen, Spruce and Grassland in Western Colorado". J. of Forestry, Vol. 63, No. 10, 1965, pp. 756-760.

Burgy, R.H. "Water yields as influenced by watershed management". J. of Irrigation and Drainage Div., Proc. A.S.C.E., Vol. 84, I.R.2, Pt. 1, 10 pp.

Colman, E.A. Vegetation and Watershed Management: An Appraisal of Vegetation Management in Relation to Water Supply, Flood Control, and Soil Erosion. N.Y.: Ronald Press, 1953, 412 pp.

Connaughton, C.A. "The Accumulation and Rate of Melt of Snow as Influenced by Vegetation". J. of Forestry, Vol. 33, 1935, pp. 564-569.

Eschner, A.R., and D.R. Satterlund. "Forest Protection and Streamflow from an Adirondack Watershed". Water Res. Res., Vol. 2, No. 4, 1966, pp. 765-783.

Forbes, R.D., and A.B. Meyer (eds.). Forestry Handbook. N.Y.: The Ronald Press Company, 1961, 1093 pp.

Golding, D.L. "Land management Practices that Affect Water Yield". Paper presented at the joint Research-Management Seminar on Managing Forest Lands for Water, Edmonton, 1970. Mimeo, 25 pp.

Hibbert, A.R. "Water yield changes after converting a forested catchment to grass". Water Res. Res., Vol. 5, No. 3, 1969, pp. 634-640.

______________. "Forest treatment effects on water yield", in Sopper and Lull, International Symposium on Forest Hydrology.N.Y.: Pergaman Press, 1967, pp. 527-543.

Hoover, M.D. "Effect of removal of forest vegetation upon water yield". Trans., A.G.U., Vol. 25, Pt. 6, 1944, pp. 969-977.

Hornbeck, J.W., R.S. Pierce, and C.A. Federer. "Streamflow changes after forest clearing in New England". Water Res. Res., Vol. 6, No. 4, 1970, pp. 1124-1132.

Hoyt, W.G., and H.C. Troxell. "Forests and Streamflow". Proc. A.S.C.E., Vol. 58, No. 6, 1932, pp. 1037-1065.

Johnson, E.A., and H.G. Meginnis. "Effect of altering forest vegetation on low flows of small streams". Proc. I.A.S.H., Publ. 51, Helsinki, 1960, pp. 257-278.

Kittredge, J. Forest Influences. N.Y.: McGraw Hill Book Co., Inc., 1948, 394 pp.

Lassen, L., H.W. Lull, and B. Frank. Some Plant-Soil-Water Relations in Watershed Management. U.S. Dept. of Agriculture, Circ. 910. Washington: U.S.G.P.O., 1952, 64 pp.

Lee, R. "Theoretical Estimates versus Forest Water Yield". Water Res. Res., Vol. 6, No. 5, 1970, pp. 1327-1334.

Lewis, D.C. "Annual Hydrologic Response to Watershed Conversion from Oak Woodland to Annual Grassland". Water Res. Res., Vol. 4, No. 1, 1968, pp. 59-72.

Lull, H.W., and W.E. Sopper. "Factors that imfluence streamflow in the Northeast". Water Res. Res., Vol. 2, No. 3, 1966, pp. 371-379.

McGuinness,J.L., and L.L. Harrold. "Reforestation Influences on Small Watershed Streamflow". Water Res. Res., Vol. 7, No. 4, 1971, pp. 845-852.

Muller, R.A. "The effects of reforestation on water yield: A case study using energy and water balance models for the Alleghany Plateau, New York:. Centerton, N.J., Publications in Climatology, Vol. XIX, No. 3, 1966, 53 pp.

Penman, H.L. Vegetation and Hydrology. Harpenden Eng.: Technical Communication No. 53. Commonwealth Bureau of Soils, 1963, 124 pp.

Rosa, J.M. "Forest Snowmelt and Spring Floods". J. of Forestry, Vol. 54, 1956, pp. 231-235.

Satterlund. D.R. "Vegetation Storage on the Watershed". J. of Forestry, Vol. 57, 1959, pp. 12-14.

Schneider, W.J., and G.R. Ayer. "Effect of Reforestation on Streamflow in Central New York". U.S.G.S. Water Supply Paper, 1602. Washington: U.S.G.P.O., 1961, 61 pp.

Sopper, W.E., and H.W. Lull (eds.) Forest Hydrology. Proceedings of International Symposium on Forest Hydrology. London: Pergamon Press, 1967, 813 pp.

Storey, H.C. "Effects of Forest on Runoff" J. of Soil and Water Conservation, Vol. 14, No. 4, 1959, pp. 152-155.

Wilm, H.G. "The influence of forest cover on snowmelt". Trans., A.G.U., Vol. 29, No. 4, 1948, pp. 547-557.

Agricultural Hydrology

Allis, J.A., and L.L. Kelly. "Runoff from Small Watersheds". Soil Conservation, 1958, p. 164.

Allis, J.A. "Comparison of storm runoff volumes from small, single-crop watersheds and from a larger, mixed-crop watershed". Agricultural Engineering, Vol. 43, No. 4, 1962, pp. 220-223.

Black. P.E. "Streamflow Increases Following Farm Abondonment on Eastern New York Watershed". Water Res. Res., Vol. 4, No. 6, 1968, pp. 1171-1178.

Brakensiek, D.L., and C.R. Amerman. "Evaluating effect of land use on Streamflow". Agricultural Engineering, Vol. 41, 1960, pp. 158-161, 167.

Dragoun, F.J. "Effects of cultivation and grass on surface runoff". Water Res. Res., Vol. 5, No. 5, 1969, pp. 1078-1083.

Dreibelbis, F.R. "Some aspects of watershed hydrology as determined from soil moisture data". J. of Geophysical Research, Vol. 67, No. 9, 1962, pp. 3425-3435.

Ferguson, W.S. "Effect of intensity of cropping on the efficiency of water use". Can. J. Soil Sc., No. 43, 1963, pp. 156-165.

Hobbs, H.W. "Runoff behaviour of small agricultural watersheds under various land use practices". Trans. , A.G.U., Vol. 27, No. 1, 1946, pp. 69-80.

Holtan, H.N., N.E. Minshall, and L.L. Harrold. Agricultural Handbook No. 224. Field manual for Research in Agricultural Hydrology. Washington: U.S.D.A., U.S.G.P.O., 1968, pp. 214.

Kohler, K.O. Jr. "Land use and vegetative cover as factors influencing runoff". Trans., A.G.U., 1944, pp. 40-44.

Krimgold, D.B. "Rates of runoff from small drainage basins". Agricultural Engineering, Vol. 28, 1947,pp. 25-28.

MacIver, I. The Land and Water Resources of the Spring Creek Basin, Some Problems of Settlement on the Agricultural Frontier in Alberta, Canada. Unpublished M.A. Thesis, Dept. of Geogr. U. of Alberta, Edmonton, 1966, 202 pp.

Melvin, E.R., J.L. Thompson, and W. Nicholaichuk. "Runoff Frequency from a Small Prairie Watershed". Canadian Agricultural Engineering, Vol. 8, No. 1, 1966, pp. 7-8, 25,36.

Potter, W.D. "Surface Runoff from Agricultural Watersheds". Highway Research Board, Research Report No. 11-B, Surface Drainage. Washington: National Research Council, 1950, pp. 21-35.

Ricca, V.T., P.W. Simmons, J.L. McGuinness and E.P. Taigonides. "Influence of Land Use on Runoff from Agricultural Watersheds". Trans., A.S.C.E., Vol. 13, No. 2, 1970, pp. 187-190.

Sharp, A.L., A.E. Gibbs, and W.J. Owen. "Development of Procedure for Estimating the Effects of Land and Watershed Treatment on Streamflow". U.S.D.A, Tech. Bull. No. 1352. Washington: U.S.G.P.O., 1966, 32 pp.

Smith. W.E. "The hydrologic behaviour of agricultural watersheds". Trans., A.G.U., Vol. 25, Pt. 6, 1944, pp. 1048-1059.

U.S. Dept. of Interior, Bur. of Recl. Water Measurement Manual, A Manual Pertaining Primarily to Measurement of Water for Irrigation Projects. Washington: U.S.G.P.O.,1971, 329 pp.

Urban Hydrology

Anderson, D.G. "Effects of Urban Development on Floods in Northern Virginia". U.S.G.S. Water Supply Paper 2001-C. Washington: U.S.G.P.O., 1970, 22 pp.

Black, P.E. "The Watershed in Principle". Water Res. Bull., Vol. 6, No. 2, 1970, pp. 153-162.

Brater, E.F. "Steps toward a better understanding of urban runoff processes". Water Res. Res., Vol. 4, No. 2, 1968, pp. 335-347.

Brownlee, R.C., T.A. Austin, and D.M. Wells. Interim Report: Variation of Urban Runoff Quality with Duration and Intensity of Storms. Texas Tech. U., Water Resources Centre, 1970, 68 pp.

Horner, W.W., and F.L. Flynt. "Relation Between Rainfall and Runoff from Small Urban Areas". Trans., A.S.C.E., Vol. 101, 1936, pp. 140-206.

Izzard, C.F. "Hydraulics of Runoff from Developed Surfaces". Proc. Highway Res. Board, Vol. 26. Washington: U.S. National Research Council, 1946, pp. 129-150.

Meyer, L.D., W.H.Wischmeier, and W.H. Daniel. "Erosion, Runoff and Revegetation of Denuded Construction Sites". Trans. A.S.A.E., Vol. 14, No. 1, 1971, pp. 138-141.

Progress Report by Task Force on effect of Urban Development on Flood Discharges. "Effect of urban development on flood discharges-current knowledge and future needs". J. Hydr. Div., Proc. A.S.C.E., Vol. 95, Pt. 1, No. H.T. 1, 1969, pp. 287-309.

Spieker, A.M. "Some observations on streamflow and water quality in the urban environment". Proceedings American Water Resources Association, 1968. Urbana, Ill., 1969, pp. 742-753.

__________. "Water in Urban Planning, Salt Creek Basin, Illinois". U.S.G.S. Water Supply Paper 2002. Washington: U.S.G.P.O., 1970, 147 pp.

Viessman, W. Jr. "The Hydrology of Small Impervious Areas". Water Res. Res., Vol. 2, No. 3, 1966, pp. 405-412.

Waananen, A.O. "Hydrologic Effects of Urban Growth-Some Characteristics of Urban Runoff". Art. 275 in U.S.G.S.Prof. Paper 424-C, 1961, pp. C353-C356.

Wolman, M.G., and A.P. Schick. "Effects of construction on fluvial sediment, Urban and suburban areas of Maryland". Water Res. Res., Vol. 3, No. 2, 1967, pp. 451-464.

Culverts and Measuring Techniques

Airport Drainage. Advisory Circular No. 150/5320-5B. Washington: Dept. of Transportation, Federal Aviation Administration, 1970, 80 pp.

Allison, S.V. "Review of small basin runoff prediction methods". J. Irr. and Dr. Div., Proc. A.S.C.E.I.R.1, Vol. 93, March 1967, pp. 1-6.

American Iron and Steel Institute. Handbook of Steel Drainage and Highway Construction Products. N.Y.: American Iron and Steel Institute, 1967, 368 pp.

A R M C O. Handbook of Culvert and Drainage Practice. The Canada Ingot Iron Ltd., 1945, 473 pp.

Bodhaine, G.L. "Measurement of peak discharge at culverts by indirect methods". Techniques of Water-Resources Investigations of U.S.G.S., Chapter A3, Bk. 3, Applications of Hydraulics. Washington: U.S.G.P.O., 1969, 60 pp.

Carter, R.W. "Computation of peak discharge at culverts" U.S.G.S. Circ. 376, Washington: U.S.G.P.O., 1957, 26 pp.

Chow. V.T. "Hydrologic design of culverts". J. Hydr. Div., Proc. A.S.C.E., Vol. 3, H.Y. 2, 1962, pp. 39-55.

Herr, L.A., and H.G. Bossy. "Capacity Charts for the Hydraulic Design of Culverts". U.S. Bureau of Public Roads, Hydraulic Eng. Circ. No 10. Washington: U.S.G.P.O., 1965, 90 pp.

Horn, D.R., and N. Dee. "A Description of Drainage Areas Gauged by the Storm Drainage Research Project". Technical Report 5, The Storm Drainage Research Project. The John Hopkins University, 1967.

Izzard, C.F. "Peak Discharge for Highway Drainage Design". Trans., A.S.C.E., Vol. 119, 1954, pp. 1005-1024.

King, H.W. Handbook of Hydraulics. N.Y.: McGraw Hill Book Co., 1954, 556 pp.

Knapp, J.W., J.C. Schaake and W. Viessman, Jr. "Measuring Rainfall and Runoff at Storm Water Outlets". J. Hydraulics Div., Proceedings. A.S.C.E., Vol. 89, H.Y.5, Pt. 2, 1963, pp. 99-115.

Mavis, F.T. "The hydraulics of culverts". The Pennsylvania State College Bulletin, Engineering Exp. St. Ser. Bull. No. 56, 1943, 34 pp.

Neill, C.R. "Hydraulic Capacity of Large Corrugated - Metal Culverts". The Engineering Journal, Feb., 1962. Reprint, 8 pp.

__________. "Hydraulic Roughness of Corrugated Pipes". J. Hydr. Div., Proc., A.S.C.E., H.Y. 3, 1962, pp. 23-44.

Normann, J.M., and H.G. Bossy. "Hydraulic Flow Resistance Factors for Corrugated Metal Conduits". U.S. Dept.of Transportation, Federal Highway Administration. Washington: 1970, 48 pp.

Ree, W.O., and F.R. Crow. "Culverts as Water Runoff Measuring Devices". Agricultural Engineering, Vol. 35, No. 1, 1954, pp. 28-31, 39.

Searcy, J.K. Design of Roadside Drainage Channels, Hydraulic Design Series No. 4. U.S. Dept. of Com., Bur. of Pub. Rds. Washington: U.S.G.P.O., 1965, 56 pp.

Straub, L.G., and H.N. Morris. "Hydraulic tests on corrugated metal pipe". University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Tech. Pap. 15, Ser. B, 1950b, 24 pp.

Thomas, C.W. "Common errors in measurement of irrigation water". J. Irr. Dr. Div., Proc. A.S.C.E., Vol. 83, Paper 1362, 1957, pp. 1362, 1-24.

Other Sources

Cohen, P. and M. Francisco (eds.) Fourth American Water Resources Conference. Urbana: A.W.R.A. Proceedings Series No. 6, held at New York, N.Y.,1968, 793 pp.

Environment Conservation Authority, Alberta. Proceedings Public Hearings on a Proposal to Restore Water Levels in Cooking and Hasting Lakes. Edmonton: Environment Conservation Authority, Alberta, 1971, 230 pp.

Hall, P.L. and E.J. Langham. Drainage Basin Study, Progress Report No.7 and Program Review. Regina: Saskatchewan Research Council, Report E70-4, 1970, 110 pp.

Laycock, A.H. Cooking Lake Brief. Paper presented to Proceedings:Public Hearings on a Proposal to Restore Water Levels in Cooking and Hastings Lakes. Edmonton: August, 1971.

Lull, H.W. and K.G. Reinhart. Forests and Floods in the Eastern U.S. Washington: U.S.D.A. Forest Service, Research Paper WE226, 1972, 94 pp.

McClellan, J.B., L. Jersak and C.L.A. Hutton. A guide to the classification of land use for the Canada land inventory. Ottawa: Geographical Branch, Dept. E.M.R.,1967, 19 pp.

APPENDIX A

THORNTHWAITE PROCEDURE - YEARLY VALUES - 89 YEARS

Year	Temp. ° F.	PE (adj) Inches	Precip. Inches	AE Inches	Deficit Inches	Surplus Snow and Rain	RO Rainfall Runoff	SMRO Snowmelt Runoff
1883	36.6	19.28	9.26	9.11	10.17	4.01	0	4.01
1884	33.6	19.03	15.03	14.93	4.10	0	0	0
1885	36.6	20.23	15.36	15.10	5.13	0.04	0.04	0
1886	34.5	20.35	13.11	14.91	5.44	0	0	0
1887	34.3	18.72	12.50	11.69	7.13	0	0	0
1888	34.7	19.04	19.93	17.94	1.10	2.82	2.06	0.76
1889	40.9	22.99	8.16	7.44	15.55	0	0	0
1890	36.6	21.22	22.01	21.22	0	0	0	0
1891	38.4	21.73	17.90	18.77	3.27	0.94	0	0.94
1892	36.3	19.73	16.85	14.66	5.07	0	0	0
1893	34.3	19.04	17.87	15.93	3.20	0.39	0.26	0.13
1894	36.8	21.14	16.13	16.65	4.49	0.83	0	0.83
1895	37.0	21.69	14.68	14.69	7.10	0.21	0	0.21
1896	34.0	20.67	15.24	13.75	6.92	0.77	0.47	0.30
1897	36.7	22.74	14.55	15.20	7.54	0	0	0
1898	38.2	21.57	10.90	11.26	10.31	0.46	0	0.46
1899	34.6	18.84	20.89	18.84	0	0	0	0
1900	37.8	21.44	27.81	21.44	0	4.69	0.43	4.26
1901	39.0	21.23	27.54	21.23	0	7.77	4.76	3.01
1902	36.9	20.49	20.66	13.96	2.53	4.39	3.39	1.00
1903	37.6	20.16	21.06	20.16	0	0.16	0.16	0
1904	36.2	21.94	19.87	17.10	4.84	4.29	0	4.29
1905	39.4	22.36	15.56	15.89	6.47	0	0	0
1906	38.9	22.97	19.17	15.34	7.63	0	0	0

APPENDIX A (continued)

THORNTHWAITE PROCEDURE - YEARLY VALUES - 89 YEARS

Year	Temp. ° F	PE (adj) Inches	Precip. Inches	AE Inches	Deficit Inches	Surplus Snow and Rain	RO Rainfall Runoff	SMRO Snowmelt Runoff
1907	35.2	18.06	16.62	17.76	0.30	3.99	0.49	3.50
1908	38.5	21.83	15.31	14.65	7.18	0	0	0
1909	33.8	20.30	12.94	13.20	7.10	0.04	0.04	0
1910	38.4	22.34	14.93	14.90	7.44	0	0	0
1911	36.0	20.32	20.67	19.73	0.59	0	0	0
1912	39.5	22.20	20.18	21.63	0.57	0	0	0
1913	37.8	21.19	19.54	19.63	1.56	0.07	0	0.07
1914	36.7	21.32	25.29	21.01	0.31	0.77	0.77	0
1915	39.7	21.54	18.64	20.34	1.20	0.60	0	0.60
1916	34.8	19.44	20.95	19.44	0	0	0	0
1917	34.6	20.15	15.25	14.15	6.00	2.55	0.70	1.85
1918	37.9	20.14	17.86	17.10	3.04	0	0	0
1919	35.5	21.41	16.43	13.23	8.18	0.17	0	0.17
1920	35.9	19.73	18.16	16.40	3.33	6.32	0.91	5.41
1921	37.1	21.31	15.22	14.63	6.68	0.23	0	0.23
1922	36.7	22.04	13.77	13.69	8.35	0	0	0
1923	38.7	21.74	17.44	17.48	4.26	0.37	0	0.37
1924	36.5	20.97	18.77	16.93	4.04	0	0	0
1925	35.9	20.02	17.44	14.16	5.86	2.79	1.18	1.61
1926	37.7	20.05	20.75	18.35	1.70	0.62	0	0.62
1927	33.1	19.55	17.68	17.20	2.35	2.52	0	2.52
1928	39.0	19.79	15.15	16.32	3.47	0.85	0.57	0.28
1929	36.3	20.58	15.12	13.04	7.54	0.55	0.55	0

APPENDIX A (continued)

THORNTHWAITE PROCEDURE - YEARLY VALUES - 89 YEARS

Year	Temp. ° F.	PE (adj) Inches	Precip. Inches	AE Inches	Deficit Inches	Surplus Snow and Rain	RO Rainfall Runoff	SMRO Snowmelt Runoff
1930	38.7	20.81	12.40	13.06	7.75	0	0	0
1931	40.0	21.26	20.04	19.67	1.59	0	0	0
1932	36.0	21.89	15.48	14.43	7.46	0.64	0.64	0
1933	34.4	20.11	21.78	17.59	2.52	1.16	0	1.16
1934	38.4	20.77	19.16	19.78	0.99	3.29	0	3.29
1935	35.1	20.01	23.79	16.54	3.47	3.67	0.16	3.51
1936	34.6	21.22	16.49	15.02	6.20	4.13	0.62	3.51
1937	35.8	22.41	19.34	19.32	3.09	0	0	0
1938	38.1	21.40	16.89	16.17	5.23	0	0	0
1939	37.3	20.04	17.27	13.64	6.40	4.27	1.46	2.81
1940	35.7	20.50	19.88	14.79	5.71	4.69	2.27	2.42
1941	38.3	21.87	15.86	16.65	5.22	0.19	0	0.19
1942	36.9	20.48	23.99	19.49	0.99	0.48	0.48	0
1943	37.9	21.23	16.56	17.74	3.49	3.12	0	3.12
1944	39.0	21.50	23.64	20.85	0.65	2.14	2.14	0
1945	34.2	19.22	14.35	13.20	6.02	0	0	0
1946	36.1	19.65	17.71	17.77	1.88	0.25	0	0.25
1947	36.3	20.95	20.42	17.12	3.83	1.47	0.72	0.75
1948	35.0	20.66	18.37	14.85	5.81	4.79	0	4.79
1949	36.1	21.51	13.58	13.37	8.14	0	0	0
1950	34.8	19.24	11.66	11.65	7.59	0	0	0
1951	32.1	17.32	23.14	17.32	0	2.37	1.53	0.84
1952	38.2	22.20	18.65	20.24	1.96	2.76	0	2.76
1953	37.8	19.78	23.12	19.78	0	1.98	1.98	0

APPENDIX A (continued)

THORNTHWAITE PROCEDURE - YEARLY VALUES - 89 YEARS

Year	Temp. ° F.	PE (adj) Inches	Precip. Inches	AE Inches	Deficit Inches	Surplus Snow and Rain	RO Rainfall Runoff	SMRO Snowmelt Runoff
1954	36.4	17.66	21.64	17.66	0	3.42	2.97	0.45
1955	33.6	19.96	20.30	16.69	3.27	2.18	1.94	0.24
1956	36.1	20.94	19.53	19.24	1.70	2.44	0.07	2.37
1957	35.4	19.54	13.48	11.93	7.61	0	0	0
1958	36.3	21.68	16.78	16.27	5.41	0.97	0	0.97
1959	37.3	19.21	17.84	17.55	1.66	0	0	0
1960	38.1	21.23	19.93	19.95	1.28	0.21	0	0.21
1961	37.2	21.73	13.47	14.13	7.60	0	0	0
1962	36.8	21.51	19.13	18.95	2.56	1.05	0	1.05
1963	35.0	19.34	15.38	14.89	4.45	0.34	0	0.34
1964	36.2	21.31	17.27	16.17	5.24	0	0	0
1965	33.9	19.83	22.04	17.69	2.14	5.42	3.53	1.89
1966	33.5	19.44	15.86	15.99	3.45	0	0	0
1967	35.7	20.49	14.92	13.17	7.32	0.28	0	0.28
1968	36.4	19.72	14.43	15.81	3.91	0	0	0
1969	34.5	20.43	16.64	15.89	4.54	0	0	0
1970	34.5	20.97	18.30	17.49	3.48	1.17	0	1.17
1971	35.4	21.44	16.82	15.04	6.40	3.32	0	1.86
Mean	36.5	20.63	17.67	16.33	4.23	1.29	0.42	0.87

Assumed 4 inch storage capacity.

APPENDIX B

WHITEMUD CREEK MEAN DAILY DISCHARGE FOR 1969

Date	Q in Cfs	Date	Q in Cfs	Date	Q in cfs
May 13	0.07	June 2	0.02	Sept. 5	0.28
May 14	2.10	June 3	0.01	Sept. 6	10.70
May 15	0.40	June 4	0	Sept. 7	4.00
May 16	0.10	.	.	Sept. 8	0.83
May 17	0.02	.	.	Sept. 9	0.08
May 18	0.05	.	.	Sept. 10	0.05
May 19	0.04	Aug. 5	0	Sept. 11	0.03
May 20	0.02	Aug. 6	0.14	Sept. 12	0.01
May 21	0.02	Aug. 7	3.40	Sept. 13	0
May 22	0.01	Aug. 8	1.20		
May 23	0.01	Aug. 9	0.68		
May 24	0	Aug. 10	0.48		
May 25	0	Aug. 11	0.08		
May 26	0	Aug. 12	0.04		
May 27	0	Aug. 13	0.04		
May 28	0	Aug. 14	0		
May 29	0.04	.	.		
May 30	0.33	.	.		
May 31	0.06	.	.		
June 1	0.03	Sept. 4	0		

Source: Water Survey of Canada.
Unpublished, preliminary Data.

APPENDIX C

WHITEMUD CREEK MEAN DAILY DISCHARGE FOR 1970

Date	Q in cfs	Date	Q in cfs	Date	Q in cfs	Date	Q in cfs
April 2	0*	April 27	15.1	May 22	.76	June 16	.10
April 3	2.0*	April 28	13.5	May 23	.46	June 17	.83
April 4	5.0*	April 29	11.1	May 24	.10	June 18	1.0
April 5	10.0*	April 30	9.3	May 25	.10	June 19	.94
April 6	42.0*	May 1	2.9	May 26	.10	June 20	.73
April 7	105.0*	May 2	2.8	May 27	.84	June 21	.47
April 8	220.0*	May 3	2.4	May 28	1.6	June 22	.12
April 9	489.0	May 4	1.3	May 29	1.8	June 23	.10
April 10	1030.0	May 5	1.3	May 30	1.8	June 24	.10
April 11	1120.0	May 6	1.0	May 31	1.5	June 25	.09
April 12	680.0	May 7	.77	June 1	1.2	June 26	.09
April 13	409.0	May 8	.87	June 2	.96	June 27	.09
April 14	263.0	May 9	.99	June 3	.81	June 28	.09
April 15	176.0	May 10	.90	June 4	.37	June 29	.09
April 16	119.0	May 11	.77	June 5	.10	June 30	2.0
April 17	88.9	May 12	2.30	June 6	.10	July 1	14.0
April 18	66.1	May 13	1.20	June 7	.10	July 2	24.9
April 19	51.9	May 14	1.60	June 8	.10	July 3	20.6
April 20	40.1	May 15	1.80	June 9	.09	July 4	17.0
April 21	33.3	May 16	1.30	June 10	.09	July 5	16.2
April 22	38.7	May 17	.82	June 11	.10	July 6	16.5
April 23	37.1	May 18	.89	June 12	.09	July 7	14.8
April 24	28.5	May 19	.88	June 13	.09	July 8	13.8
April 25	24.1	May 20	.95	June 14	.09	July 9	12.9
April 26	18.6	May 21	.91	June 15	.09	July 10	30.6

Note: *Ice conditions.

APPENDIX C (continued)

WHITEMUD CREEK MEAN DAILY DISCHARGE FOR 1970

Date	Q in cfs	Date	Q in cfs
July 11	46.3	Aug. 3	18.2
July 12	126.0	Aug. 4	15.4
July 13	144.0	Aug. 5	11.3
July 14	85.1	Aug. 6	6.3
July 15	50.6	Aug. 7	2.0
July 16	33.4	Aug. 8	1.2
July 17	24.2	Aug. 9	.86
July 18	18.5	Aug. 10	.81
July 19	17.1	Aug. 11	.10
July 20	13.0	Aug. 12	.10
July 21	12.8	Aug. 13	.10
July 22	15.8	Aug. 14	.10
July 23	10.3	Aug. 15	.10
July 24	9.1	Aug. 16	.10
July 25	9.4	Aug. 17	.10
July 26	9.3	Aug. 18	.10
July 27	11.8	Aug. 19	.10
July 28	16.9	Aug. 20	.10
July 29	17.0	Aug. 21	.10
July 30	16.4	Aug. 22	.10
July 31	24.3	Aug. 23	.10
Aug. 1	24.2	Aug. 24	0
Aug. 2	20.6		

Source: Water Survey of Canada; Unpublished, preliminary data.

APPENDIX D

WHITEMUD CREEK MEAN DAILY DISCHARGE FOR 1971

Date	Q in cfs	Date	Q in cfs	Date	Q in cfs	Date	Q in cfs
April 8	0*	May 2	11.1	May 26	.35	June 19	.78
April 9	8.0*	May 3	8.6A	May 27	.33	June 20	.51
April 10	90.0*	May 4	7.7E	May 28	.17	June 21	.29
April 11	90.0*	May 5	6.9E	May 29	.09	June 22	.14
April 12	70.0*	May 6	6.0E	May 30	.06	June 23	.08
April 13	90.0*	May 7	5.2E	May 31	.04	June 24	.10
April 14	88.1*	May 8	4.3E	June 1	.03	June 25	.08
April 15	539.0*	May 9	3.5E	June 2	.02	June 26	.08
April 16	1450.0*	May 10	2.6E	June 3	.03	June 27	.13
April 17	1450.0*	May 11	1.8	June 4	.05	June 28	.36
April 18	1210.0	May 12	1.7	June 5	.09	June 29	.33
April 19	953.0	May 13	1.3	June 6	.24	June 30	.16
April 20	652.0	May 14	.85	June 7	.12	July 1	.10
April 21	447.0	May 15	1.0	June 8	.83	July 2	.09
April 22	311.0	May 16	.75	June 9	1.0	July 3	.92
April 23	218.0	May 17	.97	June 10	2.7	July 4	4.5
April 24	150.0	May 18	.73	June 11	1.2	July 5	5.2
April 25	99.6	May 19	1.4	June 12	.48	July 6	38.1
April 26	63.1	May 20	1.1	June 13	.23	July 7	96.8
April 27	43.1	May 21	.79	June 14	.23	July 8	86.2
April 28	32.3	May 22	.70	June 15	.29	July 9	55.6
April 29	23.0	May 23	.68	June 16	.33	July 10	44.4
April 30	16.9	May 24	.63	June 17	.53	July 11	98.5
May 1	13.4	May 25	.55	June 18	.78	July 12	217.0

APPENDIX D (continued)

WHITEMUD CREEK MEAN DAILY DISCHARGE FOR 1971

Date	Q in cfs	Date	Q in cfs
July 13	227.0	Aug. 4	1.3
July 14	152.0	Aug. 5	.58
July 15	110.0	Aug. 6	.59
July 16	80.0	Aug. 7	.97
July 17	54.0	Aug. 8	.52
July 18	35.1	Aug. 9	.31
July 19	24.2	Aug. 10	.29
July 20	16.4	Aug. 11	.90
July 21	12.3	Aug. 12	1.1
July 22	9.3	Aug. 13	.53
July 23	8.7	Aug. 14	.43
July 24	10.4	Aug. 15	.31
July 25	9.2	Aug. 16	.31
July 26	8.6	Aug. 17	.13
July 27	8.0	Aug. 18	.11
July 28	8.6	Aug. 19	.10
July 29	8.8	Aug. 20	.08
July 30	4.9	Aug. 21	.07
July 31	4.2	Aug. 22	.05
Aug. 1	3.0	Aug. 23	.04
Aug. 2	2.5	Aug. 24	.02
Aug. 3	2.1	Aug. 25	0

Note: *Ice conditions; A - Manual gauge; E - Estimated

Source: Water Survey of Canada; Unpublished, preliminary data.

APPENDIX E

WHITEMUD CREEK MEAN DAILY DISCHARGE FOR 1972

Date	Q in cfs	Date	Q in cfs
March 20	0	April 7	547.0
March 21	10.0	April 8	415.0
March 22	60.0	April 9	307.0
March 23	100.0	April 10	247.0
March 24	150.0	April 11	192.0
March 25	180.0	April 12	143.0
March 26	190.0	April 13	122.0
March 27	200.0	April 14	117.0
March 28	200.0	April 15	115.0
March 29	180.0	April 16	97.0
March 30	170.0	April 17	70.0
March 31	180.0	April 18	47.5
April 1	200.0	April 19	33.4
April 2	230.0	April 20	28.6
April 3	250.0	April 21	25.0
April 4	270.0	April 22	24.1
April 5	290.0	April 23	20.8
April 6	310.0	April 24	28.6
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Source: Water Survey of Canada; Unpublished preliminary data.